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THE FORMATION OF COAL BEDS. II.*

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SOME ELEMENTARY PROBLEMS.

(Read November 3, 1911.)

It is necessary, first of all, to consider some matters to which reference is made by every one who has endeavored to explain the formation of coal beds. Too many seem to have been content with acceptance of current statements respecting the apparently commonplace phenomena and too few have thought essential a careful study of work done in recent years. The indefinite and often contradictory assertions contained in discussions, published within the last decade, compelled the writer to study the available literature and, as far as possible, to make examination of the phenomena in place. This study has led him to reject some of his cherished beliefs while it has confirmed others. At the same time, it has increased his respect for the problem, which he has undertaken to solve. The topics to be considered in this portion of the work are:

The effect of floods upon a cover of vegetation,

The phenomena of peat deposits,

The buried forests.

* Part I appeared in these *Proceedings*, Vol. L., pp. 1–116.

Each of these topics will be considered only in its relation to the main problem.

The Effect of Floods upon a Cover of Vegetation.

A torrent dashing through a narrow gorge is the poet's symbol of resistless force; a great river in flood, bearing on its surface houses, trees and other floating materials in prodigious quantity, seems possessed of almost illimitable power for destruction. These conditions, so familiar to all, have led to the conception that, in the eroding and transporting power of streams in flood, one can find explanation for the origin not only of sandstone and other inorganic deposits but also for that of coal and lignite beds interstratified with them. So much importance has been assigned to this explanation by several authors, that the phenomena must be considered in detail.

The Work of Torrents.—The torrent in full flood is an interesting spectacle but its importance in this connection is confined chiefly to its bearing on the origin of inorganic sediments.

Long ago De Luc[1] described deposits made by torrents as resembling a much flattened loaf of sugar and he employed the term "cone" to distinguish them from the talus at foot of cliffs. When a stream ceases the cutting down of its bed, the formation of a cone ends and vegetation takes possession of the surface, even of steep slopes alongside of the stream. Eventually the surface is covered with a thin coat of soil and men settle upon it. Such a cone was seen by De Luc on the right bank of the river Arc, en route from Mount Cenis into Italy. It extends from Aigue-belle to Saint-Jean de Maurienne and the line around its base is nearly three miles. It is high against the rocky wall and the surface is comparatively steep. Its history is the same with that of many others. The stream cuts a channel in the cone; occasionally, during a great flood, the banks are overflowed, but the injury is not enough to drive away the inhabitants. A fall from the walls of the gorge forms a talus against which the stream flows; water finds its way through the sands and

[1] J. A. DeLuc, "Lettres physiques et morales sur l'histoire de la terre et de l'homme," Vol. II., 1780, pp. 67–68.

renders the mass almost jelly-like. A winter of heavy snows, followed by an unusually warm spring, leads to abrupt swelling of the water and the soft mass is swept out over the surface of the cone, flowing like a flood of lava. Such were the conditions here. A village, la Chapelle, had been built; in 1752, the torrent washed out a vast mass of rock and débris, which covered everything to a depth of 15 to 20 feet, completely burying the hamlet.

In a broad valley, the effects of the torrent's work are confined to the cone, but conditions are different where the valley is narrow. A few years prior to the disaster at la Chapelle, another cone was formed in the Arc valley between Saint-Andre and Saint-Michel. The river was dammed and a lake was the result. The inhabitants of a drowned hamlet endeavored to make a canal through the dam, but the great fragments foiled them and the river was left to make its own canal. De Luc visited the locality several times. When he last saw it, the river had filled the lake with débris, through which it flowed gently, while above and below it foamed amid masses of rock. De Luc notes with some interest that on the other side of the valley, opposite la Chapelle, a torrent was still at work, building its cone. Each spring saw the surface covered by a flood, bringing down new material. Yet the trees, which had gained place and had sent their roots down amid the rock-fragments, maintained themselves against the rushing waters, laden with rocks and débris, and inhabitants of the region gathered fagots there.

Similar phenomena are familiar to all students of mountainous areas. Dejection cones, some of them enormous, are numerous along the Rhone from Viége to Martigny. The flood additions are distinct, several of the cones being deposited by streams with fall of more than 250 feet per mile. Except where new channels had been cut, the trees growing on the surface of the cones are apparently uninjured, though in some cases they have been bent by blocks of rock, whose advance they had checked. The valley of the Adige between Botzen and Rovereto presents many illustrations of similar type; in the mountain areas of the western United States such conditions are merely commonplace.

McGee's[2] observations in the Sonoran district of Arizona and Mexico are equally instructive, though dealing with a somewhat different type of phenomena. That district is within the arid region and the valleys are sand wastes, with shallow channel ways which are dry during all but, perhaps, five days in each year. The mountains are scarred by barrancas or stream-worn valleys, which end abruptly at the plain. The streams during the greater part of the year are mere threads; but, during thunder gusts or cloudbursts, the old channels are filled and new ones digged, though the flow may last but a few minutes or at the most a few hours. The stream gathers loosened rock masses in the mountains, hurls them down slopes into the barrancas, dashing them to fragments and carrying the débris to the edge of the plain. There the coarser materials are dropped, but the finer stuff is transported beyond as a sheetflood until the water disappears by absorption or evaporation. The inclination of the channel ways is not far from 300 feet per mile in the mountains, decreases to 200 feet at the edge of the plain and to 50 feet at the end of the torrential area, several miles away. The flooding of the plain has, in some cases, a width of ten or more miles.

McGee saw one of the floods in 1894. It came abruptly, a mass of water thick with sand, foaming and loaded with twigs and dead leaves. It advanced at first with "racehorse speed" but the velocity diminished quickly owing to evaporation and the flood died out in irregular lobes. The depth was not more than 18 inches on the lower border, where the width of the muddy flood was about half a mile. The noteworthy feature in this connection is that the mass of slime, moving with so great speed, had no injurious effect upon the clumps of mesquite bushes, scattered here and there over the slope. When the flowing mud reached those clumps, its speed was checked momentarily; its course was diverted and it moved alongside at twice to thrice the ordinary rate. After the flood was over, the most striking observable effect was the accumulation of twigs and branches against the clumps of shrubbery and other obstacles.

Russell's notes on the Yahtse river of Alaska, to be considered

[2] W J McGee, "Sheetflood Erosion," *Bull. Geol. Soc. America,* Vol. VIII., 1897, pp. 87–112.

in another connection, are equally in place here. That river, issuing from the Malaspina glacier as a swift flood, 100 feet wide and 15 to 20 feet deep, has invaded a forest and surrounded the trees with sands and gravel to a depth of many feet. That current, rapid enough to carry a great load of very coarse material, was not strong enough to uproot the trees and evidently it could not break off the trunks until decay was well advanced. Russell's photograph shows the conditions distinctly.

Smyth[3] has described conditions in the Adirondack mountains of New York, which are of no little importance in this connection and they will be utilized in the sequel, as the character of the region is very like that imagined for some limnic basins in Europe. Many small lakes exist in that region, varying from a few rods to three or four miles in the longer diameter. They are of post-glacial origin and, in many cases, are surrounded by high hills of metamorphic rock, whence streams with rapid fall flow in comparatively narrow valleys. Big Rock lake is typical. It is a mile and a half long, three fourths of a mile wide and is fed by streams which carry much sediment and by their deposits are changing the outline of the lake. The new area is a level marshy meadow, about a foot above the water, covered with a heavy growth of grass and carrying some small balsams and tamaracks. The lakes show every stage from pond to meadow and one of them has been changed throughout into meadow, through which its stream meanders on the way to Big Rock lake, one mile away. After heavy rains, water flows over the meadows to a depth of a foot or more, leaving a sediment of varying thickness; but the torrential streams feeding the lake, though flowing through gorges, whose steep walls are more or less densely timbered, rarely bring down trees or other vegetation.

Torrents carrying no débris do as little injury to vegetation as to the rocks over which they flow. The writer has recognized this many times in the Rocky and other mountain areas of the western United States. Clear creek in Colorado, formed by the union of streams from Gray, Torrey and other high peaks of the Front range,

[3] C. H. Smyth, "Lake Filling in the Adirondack Region," *Amer. Geologist*, Vol. XI., 1893, pp. 85–90.

is subject to abrupt rise in the early summer, when hot days cause rapid melting of the snow on those peaks. The upper streams pass over hard rocks and among huge masses which choke the channels, so that, below the union, the creek, following a rocky, mostly narrow gorge and with rapid fall, carries even in great flood comparatively little sand or silt. A rise of 10 feet within 3 or 4 hours is of frequent occurrence. The low narrow "bottom," though so often overflowed by rapidly moving water, is grassy and bears some shrubs. In some places, where the canyon widens and the stream, under ordinary conditions, flows less rapidly, one finds petty islands of detritus covered by shrubs, some of them more than 15 feet high. Clearly these plants are torrent-proof, they have maintained their place from birth. Similar conditions were observed on many other streams of like character.

A Cover of Vegetation Protects against Erosion.—Within any given district of moderate size, some streams are turbid while others are limpid even in flood time. The water may be limpid or turbid in different portions of the same stream. As the rainfall is the same throughout there must be local causes for the variation.

The process of erosion begins with the impact of a raindrop; but that impact is ineffective if the drop fall on more or less elastic material. Thus it is that a cover of decayed vegetable matter, a coating of humus, protects a slope against the erosive power of rainfall; it protects existing vegetation from removal and it may enable plants to regain hold on spaces bared by fire or other agents, even though the slope be abrupt.

Ashe[4] studied an area which has great variety of soils, as the section extends from the Archean to the Quaternary. Soils from partly metamorphosed sandy shales or from mica schist offer little resistance to erosion; in some cases they cannot nourish a sod but each supports its own type of trees. Denuded of forest, the surface is gashed quickly by rains, but when forested it loses little. The accumulation of litter or humus within the Potomac area is small

[4] W. W. Ashe, "Relations of Soils and Forest Cover to Quality and Quantity of Surface Water in the Potomac Basin," *U. S. Geol. Survey, Water Supply and Irrigation Paper*, 192, 1907, pp. 290–335.

because of climatic conditions, but it suffices to protect these soils on all except the steepest slopes. Limestone soils, occupying much of the area, are very apt to "wash" when under cultivation, but where covered with forest even the steepest slopes retain their cover of humus and the run-off water is never turbid. Sandstone soils vary much in resistance, when bared, but where they are protected by a thin cover of humus the waste is insignificant. The water of small streams flowing from forest mountain-sheds is clear and pure. The great resistance offered by humus is apparent from the figures given by Ashe. Pines growing on poor soils, rarely yield more than 2 inches; yet this protects all except the steepest slopes. Chestnut oak and white oak give but 3 inches; they too grow on poor soils, which, when exposed, are torn away rapidly. Other woods give from 5 to 6 inches of litter, which is so absorbent that for several days after a rain one can squeeze water from it as from a sponge. Ashe's observations show that this vegetable litter, in the semi-decomposed condition, is so interwoven that it not only protects the underlying soil but also itself resists removal as does a well-rooted sod. The streams coming from the humus covered area are free from vegetable matter, aside from occasional twigs and, at times, some soluble matters leached from the humus.

The White mountains of New Hampshire illustrate well the incompetence of rainfall to remove living vegetation. The rock in that region is mostly granite and the soil, formed since the glacial period, is very largely humus. The slopes are abrupt and the walls of gorges frequently show more than 50 degrees; but most of the area below timber line has a dense cover of vegetation, largely spruce. Yet rains have always been frequent and many times almost deluge-like. The covering of humus is undisturbed by those rains; even where lumbermen have cut away the forest and left their litter and the humus exposed to the fury of storms, one finds little evidence of removal.

Cloudbursts or extraordinary downpours of rain have occurred many times within this area. C. H. Hitchcock has described the flood in the Flume at Franconia, which washed away the great boulder which had been dropped by the retreating ice and had remained suspended in the Flume. That huge mass has never been found. Yet, aside from a landslide or two, the terrific rainfall left the vegetation on the steep slopes unscarred. In June of 1903, a cloudburst of unusual severity broke on the northern part of the White mountains. The roads were gullied and rendered impassable; bridges, large and small, were swept away throughout the region as the streams were filled beyond the high water mark of spring freshets; sheets of water poured down naked rock surfaces in many portions of the abrupt spaces and landslides of limited extent were produced where the slope was covered with loose material. But this vast flood of water did practically no injury to the forest-covered slopes; even débris left on the mountain side by tree-choppers was almost undisturbed.[5]

But the most noteworthy evidence in this region is found on the areas which have been burned over. When a forest fire destroys the soil near the top of a divide or on a very abrupt slope, the residue is removed quickly by rain and the granite is exposed. But if the organic matter has not been destroyed, the soil resists ordinary rains even on steep slopes. If drenching rains be delayed for a few weeks, the surface gains a cover of fireweed (*Erechtites hieracifolia*) and rain is powerless. This growth is succeeded in the following season by a dense cover of raspberry, fern and other plants, among which a cherry takes root to become the characteristic form in the third season. Birches, maples and poplars are prominent during the next season and within five years the spruces make their appearance. If drenching rains follow quickly after a forest fire, the process of restoration is merely retarded, it is not prevented.

Glenn[6] studied the problem throughout the southern Appalachians, an area of 400 by 150 miles, and his studies were extended to another area farther north, 200 by 50 miles. The examination was continued westward for a long distance down the Tennessee river, so that the investigation embraced every type from the bold

[5] Communicated by C. A. Snell of Malden, Mass., who examined the whole area within four days after the disaster occurred.

[6] L. C. Glenn, "Denudation and Erosion in the Southern Appalachian Region," *U. S. Geol. Survey, Professional Paper*, 72, 1911, pp. 15–18, 23, 24, 59, 93, 96, 99.

mountains, cut by canyon-like gorges, to broad river valleys with wide bottoms in which the streams meander. This study concerns also some matters to be considered hereafter, but they are included here for convenience of reference.

Glenn asserts that, in forested areas, erosion is at its minimum, for the soil is protected by the litter from impact of raindrops. As drops move down the slope, they are checked by the litter or are absorbed by it, and the rainfall moves so slowly through the mass that for hours after rainfall, the cover is full of water. Even such gullies as were seen have their bottoms covered with litter and plants, showing that the erosion, by which they have been produced, is very slow. Streams flowing from the forested regions rise gradually during heavy rains and fall to normal more gradually, because the litter retards flow. Such streams, even when highest, are, as a rule, but slightly discolored and that discoloration is caused in great part by macerated fragments of leaves and decaying plants, for they carry little mineral matter in suspension. Some of them remain wholly clear even when swollen to far beyond their normal stage. But removal of the forest brings about an abrupt change. The protective efficiency of even a root-matted soil is evident, for when a tree is uprooted or a road is cut, so as to break the continuity, erosion begins at once. The contrast between forested and denuded areas is so striking that no argument is needed. Grass-covered slopes may be destroyed by breaks made when a cow crosses them after prolonged rainfall, but erosion can be checked by covering the surface with litter, held in place by brush; weeds and bushes spring up quickly. The writer adds his testimony in confirmation of these observations by Glenn, for he has seen many thousands of acres of cleared land, which had been abandoned after a few years of cultivation and which now are covered by a dense growth of hard wood—and this on the steep slopes of the Virginian Appalachians.

Glenn's volume is a commentary on the protective influence of vegetation and on its resistance to erosion. The changes in the rivers since the removal of forests from their headwaters, the increased erosion, the increased destructiveness of floods owing to the greater load of inorganic matter are set forth clearly on almost every page.

This increased load has led the formerly almost limpid streams to aggrade their lower reaches, to convert once fertile bottoms into marshes or to cover them with sand and gravel. This aggrading, in many instances, forced the streams to cut new channels or a network of channels through the plain. But this lateral cutting is prevented now by planting willows, aspens, balm of Gilead and other rapidly-growing plants on the river banks down to the water's edge. The silt-laden flood does little injury to these plants and the plain itself is injured only by drowning of crops when floods come in the growing season. Glenn contrasts conditions in the Coosa and Chattahoochee basins. The former river rises in an area still forested and its waters in flood carry little inorganic matter to cause destruction; but forests have been removed from the headwaters of the latter, floods are more frequent and the accumulation of sand is very great—a condition wholly unknown one hundred years ago.

Rixon[7] gives similar testimony to the ability of humus to protect itself as well as underlying material from erosion. "The litter and underbrush among the alpine timber are very heavy, having accumulated for ages. One class of timber, having reached maturity, decays, dies and falls, only to be supplanted by another growth, which in time follows its predecessor." This is in a region where rainfalls are infrequent but extremely violent.

Tuomey[8] studied the influence of forests on surface run-off. His observations were made on four small catchment areas in southern California, where wet and dry seasons are well-marked. In December, 1899, the rainfall was 18 inches. This was at the close of the long dry season, when litter and soil alike were desiccated and each absorbed a large part of the rainfall. The percentage of run-off is given in the first column:

1. Forested	3	35
2. Forested	6	33
3. Forested	6	43
4. Non-forested	40	95

[7] T. F. Rixon, "Forest Conditions in the Gila River Forest Reservation," *U. S. Geol. Survey, Prof. Paper*, 39, 1905, p. 18.

[8] J. W. Tuomey, "The Relation of Forests to Stream Flow," *Year Book of U. S. Dep't of Agriculture*, 1903, pp. 279–288.

But in January, February and March, when the absorbed moisture in the litter was great, the contrast still remained, as appears from the second column, where the run-off from the forested areas averages only three eighths while that from the non-forested area was nineteen twentieths.

The great dunes of Bermuda have their advance checked by vegetation. A network of vines creeps over the surface and breaks the force of the wind. Clumps of grass take root in the open spaces and, within a brief period, the heavy rains can do little more than to move the sand a few inches to be piled against the obstacles. Vegetation holds its place on the loose materials until, at length, a dense growth of oleander and cedar render the deluge-like rains wholly ineffective. The same condition exists along railroads within the drift covered areas of the United States. Many of the through cuts are in drift gravels, with no trace of consolidation, yet their walls show the steady advance of plants in spite of rain and the steep slope.

The resistance which vegetation offers to erosion is manifest on a grand scale in the tropics, where growth is luxuriant and the rainfall extreme. The writer has had opportunity to examine at close range fully 200 miles of the Venezuelan and Colombian coast, much of Trinidad, about 50 miles of the Jamaican coast, as well as much of the Pacific coast of Central America. There are some localities where the rock is not consolidated and vegetation cannot maintain itself. Such as gains rooting toward the close of the wet season is killed during the dry season and rain finds only the unprotected surface on which to act. But such areas are of limited extent. The slopes along the coast are usually quite steep and the stratified rocks commonly dip at a high angle. Landslides, owing to this structure, are not rare and they leave a scar on the surface which persists for years; but aside from those merely temporary interruptions, vegetation is practically continuous on even the steepest slopes. The Jamaican conditions are especially instructive. Where vegetation was destroyed by fire in some extensive areas, Guinea grass has taken possession of even the steepest slopes, giving great spaces of bright green, which are notable features of the scenery—and this in spite of the excessive rainfall. During November of 1909, the rainfall in the mountains of Jamaica was of unprecedented volume, there being at one locality 120 inches in eight days, while in others there were 20 to 30 inches within one day. Banana plantations, with unprotected soil, were washed down the hills and the plants became projectiles with which the flood destroyed vegetation on the lowland; but the forest remained almost uninjured and the litter covering the surface around the trees was practically undisturbed. Where the land was protected by trees, damage was confined to gullies digged by fallen trunks pushed forward by the water. These gullies widened in soft materials and trees, tumbled into the torrent, were carried to the lowland, where they were deposited, pêle mêle, with mineral matter on the cultivated land. Nowhere in the whole area was there evidence that rainfall did any serious injury to either forests or the forest litter.

Cornet's[9] observations in the Congo region are to the same effect. Where the dry season is prolonged, plants are practically dried by desiccation, so that the first rains do great damage; in such localities, this is so serious that vegetation cannot re-establish itself. But, near the equator where rains are almost constant, the forest quickly reoccupies areas which man has cleared. Even in regions with a long dry season, the bottoms of the valleys, owing to dampness, become forested and that puts an end to the action of the wild waters—it may cause even diversion of streams. Clearing of forests lays the humus open and it is carried off to be spread elsewhere, there to enrich the soil. This actually occurs in many valleys, giving what Dupont has termed *terrenoir;* but in the broad alluvial valleys, where humidity prevails throughout the year, vegetable detritus accumulates on the surface and gives a formation of humus *sur place.*

It matters not where one looks, the conditions are the same. Geikie,[10] familiar with the Highlands of Scotland, where bogs in the heath stage cover great areas, says that the surface of a district pro-

[9] J. Cornet, "Les depots superficiels et l'erosion continentale dans le bassin du Congo," *Bull. Soc. Belge de Géologie,* Vol. X., 1897, Mem., pp. 44–116.

[10] A. Geikie, "Textbook of Geology," 3d Ed., London, 1893, p. 475.

tected by a thin layer of turf, is denuded with extreme slowness except along the lines of its watercourses. Indeed, the evidence is wholly clear to every one who has crossed Scotland by way of the Caledonian canal, which utilizes a chain of small lakes, fed by streams rising in the Highlands and descending with rapid fall. The lakes are not turbid, they rarely show blocks or chunks of peat where the streams enter, the only evidence of vegetable matter being coloration of the water by salts of organic acids leached from the peat. The same condition exists elsewhere in Scottish lakes.

Many years ago, Marsh[11] wrote elaborately respecting the protective influence of vegetation and the disastrous consequences following removal of forests. He recognizes that humus can absorb almost twice its weight of water, which it surrenders to the underlying soil and becomes ready to absorb more. Twigs, stems, fallen trunks and the rest oppose the rush of water and break into small streams any larger ones formed by union of petty rivulets. He cites many works, reporting official as well as private studies—all recording the same results.

In the French Department of Lozére, which was among those most seriously injured by the inundation of 1866—caused by rains, not by melting snow—it was remarked everywhere that "grounds covered with wood sustained no damage even on the steepest slopes, while in cleared and cultivated fields the very soil was washed away and the rocks laid bare by the pouring rain." Marsh cites Foster, who describes an area with slope of 45 degrees, which consisted of three sections: one, luxuriantly wooded, with oak and beech from summit to base; a second, completely cleared; a third, cleared in the upper part but retaining a wooded belt for one fourth of the height from the bottom. The surface rose 1,300 to 1,800 feet above the stream flowing at the foot. The first section was wholly unscarred by the rains; the second showed three ravines, each increasing in width from summit to base; while the third, of same superficial extent, had four ravines widening from the summit to the wooded belt, in which they became narrower and soon disappeared. He

[11] G. P. Marsh, "The Earth as Modified by Human Action," New York, 1874, pp. 232–238.

refers to his own observations that, in primitive regions, running streams are generally fringed with trees and that even now in forested areas of the United States trees come almost to the water's edge, so that the banks are but slightly abraded by the current. He cites Doni respecting the Sestajone and Lima, two streams rising in the Tuscan Appenines and flowing into the Serchio. In rainy weather the volume of the former is only about half as much as that of the latter and its water limpid; whereas the water of the latter is turbid, muddy. The drainage areas are almost equal, but the Sestajone winds down between banks clad with firs and beeches, while the Lima flows through a cultivated, treeless valley.

The writer had opportunity in 1910 to observe the effect of heavy rainfall on the steep wooded slopes in central France, where the rocks are resistant gneisses and granites—a condition much like that of the White mountains. The rainfall during that summer was not merely in excess, it was extraordinary. The showers came suddenly and often resembled the cloudbursts of mountain areas within the United States. In many parts of the area, the gorges are deep, with walls often exceeding 35 degrees, at times exceeding 45 degrees. Many gorges have densely wooded walls; many others have a somewhat scanty growth, scattered over the rocky slope with plants growing here and there in decomposed material occupying clefts or accumulated behind projecting craggy points. During some showers, the water ran off exposed places not in rills but often in broad continuous sheets and the streams were converted into roaring torrents. More than once, after one of these almost cataclysmic rains, the writer passed through some of the gorges and was surprised to find that, apparently, no injury had been done to vegetation on even the steepest slopes. Tender plants, growing in handfuls of loose material on projections, seemed to be unharmed. The streams were followed for many miles, but they had received only rare stems of trees from undermined banks and the eddies showed no accumulation of plant material. Trees, lining the streams and in many cases growing down to almost the low water line, gave no evidence of having been subjected to the force of a dashing torrent. The conditions differ from those, with which every one is familiar, only in that they are on a larger scale. The almost vertical walls of railroad cuts through hard rock are adorned by small plants growing in clefts or even by trees in similar position. These have grown in spite of rains, which threatened to wash away the little soil on which they depend. But the rains are as powerless against plants in railroad cuts as they are against plants growing in like conditions on the walls of Alpine gorges or of canyons in the Sierra and the Rockies.

River Floods.—The floods of rivers have much in common with those of torrents, for most rivers are more or less torrential in their upper reaches; but there are noteworthy differences, aside from those due to volume. The topographical conditions required for torrents are wholly unlike those amid which great rivers exist. Torrents flow, for the most part, in narrow valleys with here and there some wider portions in which are insignificant floodplains; but rivers usually flow in broader valleys, have less rapid descent and are bordered frequently by extensive floodplains. Rivers entering the Atlantic along the eastern coast of the United States empty in most cases into estuaries, which occupy the drowned lower portion of the valley and conceal the floodplain; but the condition is different in the vast interior basin where many great rivers find discharge through the Mississippi channel. Each important tributary of that stream flows for long distances through broad lowlands, which fuse with those of the Mississippi, extending from above Cairo to the Gulf of Mexico and constantly increasing in width toward the south. The coast and the interior types must be considered separately. Illustrations of river floods will be selected mostly from those of the United States, partly because the conditions seem to be unfamiliar to many, and partly because the topographical relations of the central Mississippi region are much like those supposed by some to have existed during the coal-forming periods.

Rivers of the Atlantic Coast.—Shaler,[12] in describing several northward flowing streams of eastern Massachusetts, says that the floodplain is in direct communication with the present margin of the river, so that a very slight rise sends water over the whole of it.

[12] N. S. Shaler, "Fluviatile Swamps of New England," *Amer. Journ. Sci.*, 3d Ser., Vol. XXXIII., 1887, p. 203.

The streams, though draining comparatively small areas, carry an enormous amount of water in flood time. At low water, the river extends for some distance through reedy flats on each side of the flowing stream. The swamps, which are without *Sphagnum,* may be divided into three classes: those, formed in areas so frequently overflowed and so penetrated with water that they cannot afford a site for perennial shrubs, are occupied by rushes in the lower portions and by grasses in the upper; those, occupying a narrow belt in which the grasses give place to various bushy and low growing plants, among which alders are the prevalent forms; then, in some places, a third class, a wide field of swamps, really very wet woods, covered with water not more than twice a year and usually two or three feet above the ordinary inundations. The vegetation is continuous from the lower bench to the wet woods and it is able to resist the flood, though the mass of water is very great and the current very rapid. During flood these streams are almost torrential.

The rivers of Maine tell the same story. The Androscoggin, Kennebec and Penobscot are all liable to sudden floods and the fierce rush of water is reinforced by logs cut for timber. But the banks of those streams are covered with bushes and trees to within a foot and a half of the August stage of water; the flood, though aided by the logs, has not succeeded in tearing out these trees, but the trees have seized the logs, which may be seen for long distances entangled in the bushes. Islands in the Androscoggin have trees 40 feet high, against which the floating timber has lodged.

The Connecticut river, draining a great part of the White mountains as well as of the Massachusetts highlands, flows for nearly 200 miles in a broad valley, rising in terraces. It is subject to great floods, for much of the rugged region around its headwaters has been cleared. The writer has ridden several times for a distance of 150 miles along the banks soon after high floods, which had overflowed the second bottom, 15 to 20 feet above ordinary low water. Loose material, twigs and fallen branches, which had become dry but not decayed, had been removed to be deposited in eddies or on the bottoms. But trees and bushes growing on the lower bottom or on the banks down to within a foot of low water, were not removed.

Many of those are old trees which had withstood floods for more than a century, others were very young; but the age mattered nothing, the sapling resisted as well as did the older tree, provided only that it was rooted in material that would not soften during the flood. One great flood had poured over the second bottom in the late summer when the maize had attained its height. But it did not tear the plants from the soil; pressure against the broad leaves sufficed only to prostrate the plant; none was removed.

At the same time, the effect of the flood was shown by trees on the lower bottom, for those 25 or more feet high, if slender, were bent down stream. Those with broad spreading crowns were affected by pressure at the surface of the current. No doubt, if the flood had been repeated at intervals of two or three days, not a few of those trees would have been overturned; but, once overturned against their neighbors, they would tend to protect the others by increasing the density of the mass and so acting as breakwaters to divide the flow. The flood had no effect where the vegetation was dense, the close growth evidently reducing the current to gentle movement. Croppings of peat bogs, 1 to 3 feet thick, appear at many places in the banks. Such bogs suffer no injury except by undermining; in which case, a floating log occasionally tears off a piece.

The floods of the Passaic in New Jersey and of the Susquehanna have been described in several publications. They are more disastrous than those of the Connecticut, from a pecuniary point of view; but those rivers in flood are no more effective than the Connecticut in the struggle against vegetation.

The Potomac river, though of rather rapid fall, flows in a broad shallow channel, an anomaly due in great degree to the relation between its normal stage and its freshets. The flood of June 1 and 2, 1888, the greatest on record, was described briefly by McGee.[13] The height of water at Washington was no greater than during freshets caused by ice jams, but, above the limit of tidal influence, the volume of water and height of rise exceeded any previously recorded. The

[13] W J McGee, Tenth Ann. Rep. U. S. Geol. Survey, 1890, "Administrative Report," pp. 150–152.

discharge was thirty-eight times as great as that during the abnormally wet summer of 1889; five hundred and seventy-nine times that of the average low water discharge; it closely approximated that of the Mississippi in ordinary years and was two fifths of the discharge by that river during the flood of 1858. At Great Falls, the torrent was one third of a mile wide and 150 feet deep. This was a flood of unprecedented extent, such as might not be repeated in centuries. It should afford full opportunity for determining the ability of floods to remove vegetation. As McGee entered into no detail in his administrative report, the request was made that he would give such information as seemed proper. His letter[14] is in complete detail and the following citations are taken from it.

"The most impressive river flood I ever saw occurred in the Potomac several years ago, when during June a series of rains occurred in such order about the headwaters as to raise the river far above any high stage previously recorded—indeed I inferred from its effect in bending smaller trees in connection with the undisturbed attitude of the older trees that it far exceeded any flood of the preceding 150 years. The discharge was not accurately measured, because the flow was too swift to get a weight into the water, but approximate measurements gave a discharge comparable with that of the Mississippi at ordinary stages. After the water subsided I went over the flooded ground with care; and this is what I found—the bottom being irregular, chiefly wooded, partly in field and pasture; in the woods, trees of less than, say, a foot and a half in diameter, were bent down stream and largely robbed of foliage, and a few were broken off, leaving snags; the higher trees had generally lost branches and most of their foliage (the water having risen forty to sixty feet, or well toward the tops of the highest trees); here and there, especially near the channel, a tree or clump of trees had been uprooted and swept away, though not more than say one or two per cent. of the wood in tree or branch was gone. Here and there in the woods, where the current was concentrated by rocks or large trees, a gully, generally two or three feet deep, as many yards wide and as many rods long, had been cut out; elsewhere, especially where rocks and trees had slackened the local current, there were bars and banks of sand; and generally throughout the woods there was a layer of silt, of course, left chiefly by the subsiding waters overspreading the soil—which usually was unmodified otherwise. From a little field, previously on the bottom, a short distance above Georgetown, the entire crop and the soil to plow-depth or more was removed; and in a sloping and somewhat rocky tract of pasture land, upstream from the field, the sward was irregularly furrowed by gullies ordinarily a few feet deep and as many yards wide—the number being such

[14] Of December 6, 1910.

that perhaps a quarter or perhaps a third of the sward was removed. The furrowing in this pasture, by the way, represents the most extensive flood removal of sward that I have ever seen. Now considering the translocation of material generally by the flood, it is clear that despite the favorable conditions due to abundant vegetation and to a higher declivity of the flood than that of the normal stream, the ratio of organic matter moved to the inorganic sediment was trifling. . . . What is true of that flood is, I am convinced, true of river floods generally—while the flooded river generally has its transportative capacity greatly increased, the material transported is chiefly inorganic, so that the resulting sediments are mainly mud, silt or sand, rather than organic accumulations."

The writer rode through much of the area two months after the flood had subsided. The chief evidence of great flood presented by the vegetation consisted of somewhat inclined trees, deposits of débris in branches of trees at a distance above the stream and an occasional furrow in the sod. These furrows were produced when the water in swirling around a projecting rock worked under the sod and, soaking the materials below, burst the cover, so opening the way for making a gully. In the forested portions, the litter seemed to have suffered very little injury beyond, as noted by McGee, receiving a cover of inorganic sediment.

Murphy[15] has described a flood on Willow creek in Morrow county, Oregon, a stream combining the features of a torrent with those of a river. The creek, 30 to 40 feet wide and enclosed in banks 10 to 15 feet high, has a fall of 38 feet per mile, but, unlike most of such streams, it flows through a fertile valley, 500 to 1,500 feet wide. The storm causing the flood of 1903 was brief, a cloudburst, and the flood had passed in less than an hour. The water came down as a mass, 20 to 25 feet high, with a slope in front of about 30 degrees, and it was 500 feet wide. It swept away a great part of a town which was in its path. No details are given respecting the damage done to vegetation, but some incidental remarks make the matter sufficiently clear. Referring to methods of determining the high-water level of floods, he says that trees are the best marks; small trees are often bent over and silt or light drift is deposited on them. When the water pressure is removed, the trees straighten up

[15] E. C. Murphy, "Destructive Floods in the United States in 1903," U. S. G. S. Water Sup. and Irr. Paper, 96, 1904, pp. 9–12.

and the drifted material is raised above the high level; but rings of silt left on trees, all on approximately the same level, show the true waterline. In this way he determined the extent of the flood. The houses, made of lumber, were lifted from their foundation and were dashed to pieces against rocks or trees.

Wilkes[16] made use of the same method. In speaking of floods on the Willamette river of Oregon, he says that the sudden rises of the stream are remarkable, the perpendicular height of the flood being at times as much as 30 feet, the limit being marked very distinctly on trees along the banks. In New South Wales "near the source of streams, grass is to be seen attached to the trunks of trees thirty feet above the present level of the water, which must have been lodged there by very great floods." This is a commonplace condition; the writer observed it at the head of Sacramento bay in California almost forty-five years ago. He saw many bunches of drift stuff entangled in branches of trees at 10 to 15 feet above the water level, and he was astonished by the fact that so great a flood had done no injury even to the shrubs growing among the trees.

Rivers in Great Interior Basins.—Excellent descriptions of floods within the Mississippi-Missouri area are given in reports of the United States Weather Bureau, those by Morrill and Frankenfield[17] being the most comprehensive.

Man's skill has brought about great changes in the lowlands of the Mississippi. The fertility of that region from the mouth of the Ohio to the Gulf of Mexico early led to settlements at many places. But the periodic floods of the river rendered agricultural operations precarious and levees were constructed for protection. Eventually the construction of such levees was assumed by the Federal government and they now protect a vast area from overflow. The region, now exposed to devastation under ordinary circumstances, is very small, but, during abnormal floods, the levees sometimes give way and

[16] C. Wilkes, "Narrative of the United States Exploring Expedition," 1845, Vol. IV., p. 358; II., p. 269.

[17] P. Morrill, "Floods of the Mississippi River," Rep. Chief of Weather Bureau for 1896–7, Washington, 1897, pp. 371–431. H. C. Frankenfield, "The Floods of the Spring of 1903 in the Mississippi Watershed," Weather Bureau Bull., 1904.

crevasses are formed—at times half a mile wide—through which a stream pours with amazing velocity. The conditions are materially different from those prior to settlement of the region, when the floodwaters spread over an area of 100,000 or more square miles; the energy of the flood stream, when it bursts through a crevasse, is much greater than when there were no levees. This, however, is unimportant, for if the later floods are incompetent to inflict serious injury upon lands protected by vegetable cover, the incompetence must have been more marked when the natural conditions existed.

The protection afforded by levees is shown by constant decrease in extent of the flooded area; the flood of 1887 overflowed almost 30,000 square miles below the mouth of the Ohio; that of 1897 covered somewhat more than 13,000, while the area was reduced in 1903 to somewhat less than 7,000—and in this year the extent would have been much less if the new levees at critical localities had been completed so as to resist the very high water. Rivers carrying much detritus and subject to flood build low levees in their passage through the lowlands. The Mississippi constructed such ridges for long distances, thus preventing return of the floodwater, much of which is ponded in swamps and gradually finds its way to the river farther down. This secondary drainage complicates the problem of reclamation.

The Mississippi floods, unlike those of the Nile, are very complex, for below the mouth of the Ohio the river receives great tributaries from the east and the west, whose floods rarely coincide; while the upper Mississippi, receiving the Missouri and other rivers, has its own periods of flood. The source of floodwaters is in the continental storms, arising in the west or southwest and moving toward the east-northeast. The effects are felt first in the lower Mississippi, which is filled by streams entering from the west; the storm advances to the western ridges of the Appalachian where rise streams forming the Ohio, Cumberland and Tennessee rivers. The heavier rains on the Appalachians pour out chiefly through the Ohio but the other streams contribute a great mass. Important floods in the eastern tributaries occur in the spring months, when heavy rains are reinforced by melting snow. The upper Mississippi is not an important factor in respect of quantity, but its swell, coming later than the others, often prolongs the stage of high water. The western rivers, entering below the mouth of the Ohio, are the Arkansas, Red, Ouachita and Yazoo, all of which descend into lowlands, where they meander for a long distance before reaching the Mississippi. The condition in this drainage area is that of rapidly flowing streams emerging from highlands on an immense area of lowland, most of which, unless protected, is subject to overflow.

Both Frankenfield and Morrill emphasize the gradual rise of floods within the open area. Frankenfield gives the record for 1903. The gauge showed at

	Feet.		Feet.		Feet
Cairo, Jan. 28,	17.5	March 8,	45	March 15,	50.6
Memphis, Feb. 1,	10.8	Feb. 22,	33	Mar. 20,	40.1
Vicksburg, Feb. 4,	21.0	Mar. 3,	45		
New Orleans, Feb. 8,	9.1	Feb. 26,	16	Apr. 6,	20.4

The advance was deliberate, the first wave requiring four days for passage from Cairo (at the mouth of the Ohio) to Memphis and seven days thence to New Orleans. The rise was gradual at Cairo, being a foot and a half daily for 39 days to March 8—which was thought to be remarkably rapid—and much less thereafter to the crest; at Memphis, it was one foot for 21 days and only one fourth of a foot for each of the remaining 28; at Vicksburg, barely nine tenths of a foot during each of the first 27 days; while at New Orleans, the daily rise averaged little more than one fifth of a foot throughout the whole period. The great mass of the water came from the Ohio, but the Red and Ouachita, entering from the west, were abnormally high; at New Orleans, the water was at or above danger line for 85 days.

When one studies the reports of local observers, as given in the publications from which this synopsis is taken, he is surprised by the nature and extent of damage within the flooded areas. Artificial protection is almost unknown along the upper Mississippi (above Cairo) as well as along the Missouri and its tributaries. Floods have free course in the low-lying prairie regions of Illinois, Iowa and Kansas as well as in portions of Missouri, and there one should expect to find record of the greater disaster. Morrill has compared the flood of 1897 with its predecessors as far back as 1858 and he has given details in all parts of the drainage area for that of 1897.

In 1897, the Ohio river was out of its banks everywhere from Pittsburgh to Cairo and the tributary streams, also in high flood, were miles wide for long distances, the "bottom," at times, being covered with 20 feet of water, while the overflow reached into the upper portions of cities along the banks. At the mouth of the river, the lowland was flooded for 4 to 6 weeks and the city of Paducah in Kentucky was flooded for 7 weeks. The river rose 50 to 60 feet along the whole distance of more than 600 miles from Pittsburgh to Cairo. Similar conditions prevailed along the Tennessee river, which for 60 miles was 2 miles wide, reaching to the hills on both sides. In the upper Mississippi region, the river spread from bluff to bluff, 3 miles wide for 147 miles along the Iowa border, and a great area of farming land in that state was inundated. Imperfect levees gave way and along the Illinois river an area of 500 square miles was flooded, making a continuous body of water from the Illinois to the Mississippi. Central Arkansas was submerged for long distances along the Arkansas river; while below Cairo, several levees gave way and the flooded district in that region embraced more than 13,000 square miles.

When one comes to sum up the effect of this disastrous flood, as given by the local observers, he discovers, that as far as the geologist is concerned, they were comparatively insignificant. The damage to manufacturing interests by destruction of machinery and by deposits of mud in mills was very great; the railroads lost much through washing out of embankments, the ruin of bridges and the removal of ties and lumber; but loss to the farming population was only moderate because Weather Bureau warnings led them to transfer movable property to higher land. Small houses, barns, lumber and other loose material were floated off to be used as battering rams against bridges; but, for the most part, farms overflowed by the rapid current were little injured. Where wheat had come up, it was drowned, not removed; where seed had been sown, it rotted; where the flood became sluggish, it left a deposit of sand, which made the land worthless, but elsewhere, as soon as the water withdrew, the farmer immediately set about replanting. The great flood had done little injury, had hardly disturbed the soil of cultivated fields.

Frankenfield tells the same story for the flood of 1903. The sunken area of New Madrid was filled and the water, being more or less ponded, left deposits of sand. In the lower Mississippi area, crevasses permitted great overflow, but there was no injury to farms, aside from drowning of the crops, for which there was ample compensation in the form of a rich alluvial deposit. The Ohio river was more than two miles wide in many places between Cairo and Louisville. Near Evansville, Indiana, 300,000 acres of maize and 30,000 acres of wheat were covered, but the only loss was that of 3,000 acres by drowning. The local observer at Evansville reported that the damage would have been much greater if the water had not remained in constant motion. At Topeka in Kansas, the flood was diverted from the river by obstructions piled against a railroad bridge and the water, loaded with sand, swept over a wide area. Crops were ruined and the nursery fields near Topeka were covered with sand which buried the young trees. These instances are merely illustrations of conditions prevailing throughout the whole area.

The reports contain no reference to the disastrous effects of such floods upon areas covered with forest or otherwise protected by close vegetable growth, which at first glance seemed strange, because wooded areas occupy much of the lowland or bottom regions. But the omission was due not to neglect but to absence of anything to record. Reproductions of photographs given by Frankenfield and Morrill show that trees and even shrubs were undisturbed amid the rush of water and coarse sand. The writer asked the former for information respecting the matter. The reply was

"During the Mississippi floods no forests are uprooted and no bogs are torn away. A considerable quantity of sand is sometimes carried down and deposited when the velocity of the water decreases, either by contact with obstruction or by reason of decrease in inclination of the floodplain. It is of course conceivable that the mass of water rushing through a crevasse carries away a quantity of vegetable matter and perhaps some trees, but the area would necessarily be limited. The true Mississippi flood moves along very sedately, carrying only the enormous amount of alluvial matter in suspension, but very little indeed of foreign matter. Previous to the era of levee construction, the forests do not appear to have been seriously disturbed by floods."

An observation by McGee[18] is in place here. The Mississippi, as it flows past northeastern Iowa, meanders through a densely wooded floodplain, four or five miles wide, now in one main and half a dozen subordinate streams and yet again in numerous large and small channels. But this plain is flooded each year; according to writers already cited, the river at times covers the whole plain from bluff to bluff as a rapid stream.

Lyell,[19] in referring to the 1844 crevasse near New Orleans, says that the water poured through at the rate of ten miles an hour, inundating the low cultivated lands and sucking in several flat boats, which were carried over "the watery waste" into a dense swamp forest. He mentions that the great Carthage crevasse was open during eight weeks and that nothing was visible above the flood except the tops of cypress trees growing in the swamp.

Humphreys and Abbot[20] state that the bottoms of the Illinois river are two to ten miles wide and raised only a few feet above the usual level of the river. The greatest part of this swampy country is included in the "American bottom." The Kaskaskia flows with crooked course through a heavily wooded alluvial bottom, overflowed eight or ten feet by freshets. These authors emphasize the fact, too often ignored, that lowland areas are usually well soaked by rains preceding the floods and the swampy areas become covered with water, so that when the overflow comes, it finds everything prepared for resistance.

Lyell[21] had the weird experience of descending the Alabama river in time of high flood. At night the passengers were startled by crashing of glass and partial destruction of the steamer's upper

[18] W J McGee, "Pleistocene History of Northeastern Iowa," Eleventh Ann. Rep. U. S. Geol. Survey, 1891, p. 204.

[19] C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. II., p. 169.

[20] A. A. Humphreys and H. L. Abbot, "Report upon the Physics and Hydraulics of the Mississippi River," Reprint, Washington, 1876, pp. 38, 66, 76, 82.

[21] C. Lyell, "Second Visit," etc., Vol. II., pp. 51, 141.

works. The boat had "got among the trees." The river banks are fringed with canes over which deciduous cypresses tower, while farther back is the evergreen pine forest. During floodtime, the actual channel is very narrow, as the branches of the high trees stretch far over the water, so that, when the stream has risen 40 or 50 feet, much skill is required to keep the way between them. At that time, the adjoining swamps and lowlands are inundated far and wide. But this flood does practically no injury to the forest directly in the path of its strongest current or to that farther back where the current is less rapid. Lyell found the same condition on the Mississippi delta, where the flood waters, though laden with silt, have not injured even the willow saplings.

The floods of great rivers in other lands exhibit the same phenomena.

According to Humboldt,[22] the floods of the Orinoco begin soon after the vernal equinox and attain their maximum in July. The water remains at practically the same height until August 25, after which it falls more slowly than it rose. Its bounding region is much like that of the lower Mississippi and the flooded area is as large as England though less than the exposed region along the Mississippi. The delta area is always wet except in some petty elevations, which are dry for brief periods. The surface is completely inundated during several months each year. But it is covered with a dense growth of Mauritius palm in which the inhabitants construct raised platforms, on which they reside.

Wallace[23] has described the broad level area extending to 20 or 30 miles from the main stream of the Amazon and extending for long distances along the main tributaries. This is flooded at every time of high water. It is "covered with a dense forest of lofty trees, whose stems are every year, during six months, from ten to forty feet under water." Much of the flooded area at the mouth of the Amazon is covered with the mirite palms, *Mauritia flexuosa* and *M. vinifera.*

[22] A. Humboldt, "Personal Narrative," Bohn Eng. Ed., 1852, Vol. III., p. 8.

[23] A. R. Wallace, "A Narrative of Travels on the Amazon and Rio Negro," London, 1853, pp. 410, 436.

Kuntze[24] sailed along the Lourenço river through the vast wooded swamp occupying three degrees of latitude. The remarkable feature, for him, was the absence of transported vegetable detritus. Rare fragments of the swamp are torn off during high water, but these consist not of detritus but of living plants; and these fragments become stranded elsewhere or go to sea broken into bits. The river water is brownish. Everywhere on the Paraguay as well as on its tropical and subtropical tributaries, one finds the dense forests coming down to the river, which are overflowed during floodtime; yet there is no outgoing organic detritus except fragmentary driftwood from trees, which tumbled in from undermined banks. Kuntze followed all the great streams above the mouth of the Parana.

Livingstone[25] has given admirable illustrations of the resistance offered by vegetation. Many times he encountered the rivers in flood, when water spread far over the plains. The conditions within the area of the Chobe and in that of the Lecambye are of the familiar type. He reached the Leeba river at the beginning of the rainy season. The river is bordered by a plain, at least 20 miles wide, where, at that time, the water was already ankle deep in the shallower parts, while on the Lobale plain it was thigh deep and impassable. This flooding was not due to the river, for that had not overflowed its banks. The condition was the same as that observed prior to the coming of great floods in the Mississippi lowlands. The Lobale plains are too nearly level to permit the rain water to flow off rapidly; while the thick sward, so dense as to conceal the water, prevents furrowing of the surface and formation of rivulets. On approaching the Kasai river, he crossed valleys, half a mile to a mile or more in width, with clear fast-flowing water almost chin deep. One, half a mile wide, was deeper and the men crossed it by seizing the tails of their oxen. The extremely rapid current "soon dashed them against the opposite bank." The middle of the flood was where a rivulet exists during most of the year. Boggy places are extensive

[24] O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 67, 68.

[25] D. Livingstone, "Missionary Travels and Researches in South Africa," New York, 1858, pp. 191–195, 234, 235, 333, 363, 364, 392.

on both sides of the river, but "even here, though the rapidity of the current was very considerable, the thick sward of grass was 'laid' flat along the sides of the stream and the soil was not abraded so much as to discolor the flood." In his later work,[26] he offers an explanation of the conditions.

"The shallow valleys, along the sides of which the villages are dotted, have, at certain seasons of the year, rivers flowing through them, which at this time formed only a succession of pools, with boggy and sedgy plains between. When the sun is vertical over any part of the tropics on his way south, the first rains begin to fall and the effect of these, though copious, is usually only to fill the bogs and pools. When on his way north he again crosses the same spot, we have the great rains of the year, and the pools and bogs, being already filled, overflow and produce the great floods which mark the Zambesi, and probably in the same manner cause the inundations of the Nile. The luxuriant vegetation, which the partial desiccation of many of these rivers annually allows to grow, protects these bottoms and banks from abrasion, and hence the comparative clearness of the water in the greater floods."

Darwin and Mrs. Agassiz tell a similar story respecting the Parana and the Amazon; Cameron and Stanley have shown the conditions in the region of Lake Tanganika and the Sudd of the Nile has been described by Baker, Willey and other travellers. Everywhere, the conditions are the same; living vegetation and even humus are practically proof against the action of floods.

The Plant Materials Transported by Rivers.—While it is true that a vegetable cover is an almost complete protection against erosion and that neither rain nor floods have much ability to remove rooted plants or to take off the superficial coat of decayed or decaying plant-stuff, still the fact remains that rivers do carry away great quantities of plant materials in one form or another. The quantity brought down by a single torrent may be insignificant; even that borne by a river of considerable size may not impress an observer as important; but when one reaches the lower Mississippi, draining an area of not less than 1,250,000 square miles, fed by tributaries from the Rockies at the west and the Appalachians at the east, which flow for long distances in broad alluvial plains, he finds a

[26] "Narrative of an Expedition to the Zambesi and its Tributaries," New York, 1866, p. 554.

mass which seems to be almost inconceivably great. On some streams he finds or learns of huge log barricades, apparently affording ample confirmation of Ochsenius's barricade theory; along others the river bed is set with "snags," impeding navigation; while along the main stream the casual observer is apt to regard the floating trees and other débris as an almost continuous mass.

It is equally certain that a vast amount of finely divided vegetable matter, derived from chafing of logs and trunks during their voyage as well as from partial decay of the floating plants, is carried by all rivers. It is true that studies of the Mississippi, in flood and in ordinary stages, have shown that the quantity in the silts is utterly insignificant when compared with the inorganic materials, but it suffices, during decay, to give off a notable discharge of gas in the outer area of the delta. The suggestion has been made that vegetable matter, minutely divided, may explain the fertility of the Nile deposits. According to Reclus, cited by Marsh,[27] it has been computed that the Durance river, fed by torrents of great erosive power, carries down annually enough solid matter to cover 272,000 acres with a deposit two fifths of an inch thick, containing more available nitrogen than 110,000 tons of guano and more carbon than could be assimilated by 121,000 acres of woodland in one year. The black waters of the Scottish lakes, of several rivers in Florida, of great rivers like the Congo in Africa, the Negro and others in South America prove that an enormous amount of vegetable material is leached from peaty deposits.

When one considers the mass of transported timber, the content of organic matter removed by solution, and reads the more or less crude estimates of organic stuffs in the detritus carried by rivers, the mind is staggered and he is almost ready to concede that in this transportation there is the process fully competent to bring about the accumulation of coal beds. It is important, then, to ascertain, if possible, what becomes of this material.

The trees and shrubs carried by the rivers were not uprooted by the torrents; they come not from abrupt slopes but from lowlands where meandering streams undermine their banks and the plants

[27] G. P. Marsh, "The Earth as Modified by Human Action," p. 245.

tumble in with the rest. Gibbs,[28] who saw the spring flood of the Yukon river in Alaska, relates that

"During the high stage of water, which lasts for perhaps two or three weeks, great sections of the heavily wooded banks are undermined and swept away. The majestic spruce trees and tamaracks and birches, which covered them, topple over and are swept down by the current along with immense quantities of drift wood from the forest beds. The entire accumulation, amounting to thousands of cords of wood, is discharged into Bering sea, whose restless waves and shifting winds scatter this fuel and pile it on barren shores, hundreds of miles distant."

The conditions along the Mississippi-Missouri and their tributaries are the same; when the weakened banks cave, the forest, with its fallen trunks and litter, finds its way into the water. The masses of drifted wood in the channels of the Mississippi and some of the streams entering that river from the west have been mentioned in nearly all textbooks on geology during the last seventy-five years; but in most instances the descriptions have been incomplete, while in some cases they were sufficiently inaccurate to be misleading.

In the early days, great numbers of waterlogged trees were held back by their roots and were moored in the silt with their usually branchless stems pointing down stream. These were the "snags" which rendered navigation perilous. Fewer of them are encountered now because a very great part of the drainage area is under cultivation, but enough are added annually to necessitate the services of several snag-removing boats along the line of nearly 2,000 miles. Most of the floating stems find their way to the Gulf, but some are stranded on the delta during floods. At one time, however, they were diverted, in chief part, into the Atchafalaya, the first great arm of the river at the head of the delta.

Darby[29] has told us that the vast number of trees brought down by the Mississippi were thrown into this arm, through which they were carried with tremendous speed. The Atchafalaya raft began to form in 1778, when practically the whole drainage area of the

[28] G. Gibbs, "The Break-up of the Yukon," *Nat. Geog. Mag.*, Vol. XVII., 1906, pp. 268–272.

[29] W. Darby, "A Geographical Description of the State of Louisiana," 2d Ed., New York, 1817, pp. 131–133.

river had still its virgin forest, there being only a few, insignificant settlements west from the Alleghany mountains. By 1816, the head of the raft was within 27 miles of the Mississippi. Darby examined it in that year and reported that it was 20 miles long, 220 yards wide and perhaps 8 feet deep. As it was not continuous, but showed many open spaces, he was convinced that a length of 10 miles would be nearer the truth, thus giving about 4,000,000 cubic yards of loose material as the total accumulation during almost 40 years, practically the total supply of floated timber from the area of more than 800,000 square miles. He says that "the tales which have been related respecting this phenomenon, its having timber of large size and in many places being compact enough for horses to cross, are entirely void of truth. The raft, from frequent change of position, renders the growth of large timber impossible. Some small willows and other aquatic bushes are frequently seen among the trees but are too often destroyed by the shifting of the mass to attain any considerable size." The channel was opened by the state authorities in 1840 and the raft disappeared.

Details respecting variation of position and duration of material were not given by those who described the Atchafalaya raft. But no such lack of information exists respecting the more celebrated raft of the Red river in Louisiana. That stream, formed by tributaries rising in the higher lands of Texas and Oklahoma, flows for a long distance through a region of yielding materials, which, in many places, is densely forested. According to Veatch,[30] this raft began to form in the fifteenth century and by the beginning of the sixteenth, its head was near the present town of Alexandria, somewhat more than 60 miles from the Mississippi river. It consisted of a series of complex logjams, each filling the channel. These ponded the river, which found a new outlet above the raft, so that this, by additions, gradually moved stream, becoming a great irregular accumulation of logjams and open water about 160 miles long.

[30] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," U. S. G. S. Professional Paper, 46, 1906, p. 60.

At the time of the early settlements, the foot of the raft was at Natchitoches, 120 or 130 miles from the Mississippi.

Humphreys and Abbot,[31] writing in 1861, reported that the raft was an enormous accumulation of drift logs, some floating, some sunken. The rotting of the logs at the lower end and fresh accessions at the upper end led to advance up stream at the rate of from one mile and a half to two miles each year, while the retreat at the lower end was about equal to the gain above. At one time, the lower end was at Natchitoches but in 1854 it was at 53 miles above Shreveport, a retreat of about 150 miles. At that time, it was nearly 13 miles long. Above Shreveport to the raft, the river bed was strewn with logs, stumps and other vegetable débris. The river is very shallow, 3 to 4 feet deep at low water, and it was about 220 yards wide at the head of the raft, 405 miles from the Mississippi. Rotting would cause the 13 miles, reported by Humphreys and Abbot, to disappear within seven or eight years.

The notes given by Humphreys and Abbot were from a casual examination by their assistant, the matter lying outside of the scope of their work. The raft was a serious obstruction to navigation, cutting off the region above from communication with the Mississippi. Congress in 1871 ordered a complete survey, which was made by Lieutenant Woodruff, whose report, rendered in 1872, gave the first exact information respecting the actual conditions. Captain Howell,[32] in transmitting the report, remarks that the facts have been misapprehended even by engineers. "The 'great raft' itself dwindles to a mere pigmy in comparison with the popular notion of its extent and composition." Woodruff, in 1871, proved that the raft extended along the river for about seven miles, but that throughout that distance the channel is only partially obstructed. The whole mass of floating raft was but 290 acres and the whole area of "towheads" or raft resting on the bottom was 103 acres. The towheads are formed during freshets by accumulations of logs and drift around a "snag." As the water falls, the pile rests on the bottom and a

[31] A. A. Humphreys and H. L. Abbot, "Physics and Hydraulics," etc., 1876, pp. 21–23.

[32] C. W. Howell, 42d Congress, 2d Session, Exec. Doc., 76, p. 1.

rapid deposition of mud takes place around it. The surface left above water produces willows, which, growing rapidly and binding the mass together by their roots, protect it from the washing by subsequent freshets. Woodruff advised removal of the raft, but, to prevent renewal, he recommended that the narrow part of the river, in which the raft was forming, be cleared of the willows lining the banks, which obstructed the passage of large bodies of floating drift. If this were done, the banks, no longer protected by the vegetable growth, would cave readily, the river would be widened and the formations of raft would cease. The removal of the raft was completed in 1872 and Woodruff afterwards gave a full history of the obstruction, to which the reader is referred for other details.[33]

Franklin[34] found much floating timber on the Athabasca river in northwestern Canada. "The river carries away yearly large portions of soil, which increases its breadth and diminishes its depth, rendering the water so muddy that it is hardly drinkable. Whole forests of timber are floated down the stream and choke the channels between the islands at its mouth." It is clear that, on the Athabasca as on the Mississippi, caving banks yield the supply of drifting timber. In the same volume, Richardson[35] describes conditions observed along some rivers and lakes within the region traversed by Franklin's expedition. His statements have been cited by many writers but so far as the present writer has seen, not in full. They are as follows, with omission only of some details which are irrelevant here. Peace river brings much large drift timber into Slave river

"and as the trees retain their roots, which are often loaded with earth and stones, they readily sink when water-soaked and, accumulating in the eddies, form shoals which ultimately augment into islands. A thicket of small willows covers the new-formed island as soon as it appears above water and their fibrous roots serve to bind the whole firmly together. The trunks of the trees gradually decay until they are converted into a blackish substance

[33] E. A. Woodruff, in App. Q, Ann. Rep. Chief of Engineers for 1873, Separate, pp. 45–61.

[34] J. Franklin, "Narrative of a Journey to the Shores of the Polar Sea," London, 1823, pp. 192, 357, 364, 374, 381.

[35] J. Richardson, Ibid., p. 518.

resembling peat, but which still retains more or less of the fibrous structure of the wood, and layers of this often alternate with layers of clay and sand, the whole being penetrated to the depth of four or five yards or more by the long fibrous roots of the willows. A deposition of this kind, with the aid of a little infiltration of bituminous matter, would produce an excellent imitation of coal, with vegetable impressions of the willow roots. The same operation goes on in a much more magnificent scale in the lakes. A shoal of many miles in extent is formed on the south side of Athabasca lake by the drift timber and vegetable débris brought down by the Elk river; and the Slave lake itself must be filled in process of time by the matters daily conveyed into it from Slave river. Vast quantities of drift timber were buried under the sand at the mouth of the river and enormous piles of it are accumulated on the shore of every part of the lake. The waves washing up much disintegrated vegetable matter, fill the interstices of these entangled masses and in process of time a border of spurious peat is formed around the various bays of the lake."

In a later work,[36] referring to the drift timber of Slave river, he describes the trees as "partially denuded of their branches and wholly of their bark." The absence of all-important details in Richardson's account is due to the fact that he was not a geologist, but he was an acute observer, as is evident from the general tenor of his reports. McConnell[37] has supplied many of the details omitted by Richardson. The sandy beaches and islands along the lower reaches of Slave river owe their origin to drift timber, which lodges and soon has the growth of willows noted by that author. But those islands cause currents, which either destroy them or move them down stream. Beds of drift timber alternate with clays and sands on many of the islands and in some instances, constitute a considerable portion of the whole mass. The east end of Big island in Great Slave lake is fringed by a wide margin of drift timber. When the interstices have been filled by gradual deposition of sand and the decay of the wood, a dense growth of willows covers it. The coves of the main shore show the same features in many places. Athabasca and Slave lakes are inland seas, larger than Lake Ontario.

Islands, such as those described by Franklin, are not unusual in

[36] J. Richardson, "Arctic Searching Expedition," London, 1851, Vol. I., p. 142.

[37] R. G. McConnell, Ann. Rep. Geol. Survey of Canada, N. S., Vol. IV., 1890, pp. 63, 64, 74 D.

the Mississippi river. Humphreys and Abbot[38] have described the process of formation and destruction:

"Driftwood is lodged upon a sandbar. Deposition of sediment follows. A willow growth succeeds. In high water, more deposition is caused by the resistance thus presented to the current. In low water, the sand blown by the wind lodges among the bushes. An island thus rises gradually to the level of highwater and sometimes even above it, sustaining a dense growth of cottonwoods, willows, etc. By a similar process the island becomes connected with the mainland, or, by a slight change of direction of the current, the underlying sandbar is washed away, the new made land caves into the river, and the island disappears."

When in the temperates such an island, which in spite of current and flood, had grown and had become coated with trees, disappears through undermining, the vegetation floats away piecemeal; but in the tropics the whole mass is bound together firmly by climbing and other plants, whose roots are interlaced and whose stems embrace the trees; so that, when the underlying loose material has been removed, the entangled vegetable matter floats away to be broken up gradually. Many travellers have referred to floating island of plants and plant material. Humboldt saw them on the Orinoco; Mrs. Agassiz was astonished by their size on the Amazon, where some were like "floating gardens, sometimes half an acre in extent." Kuntze saw patches of moderate size floating down the Parana system. Miss Kingsley[39] relates that during high water, the Congo and Ogowé tear away their banks in the region above brackish water, where there is no network of mangrove to protect them. Along the Ogowé, the banks are of "stout clay" and the blocks hold together, so that they often go sailing out to sea and are seen far from land with shrubs or even trees on them. Not all reach the open water, for many are stranded in the delta region, where they collect débris from the flood water and become matted with floating grasses. Eventually they all go to pieces.

De la Beche[40] cites Tuckey's Expedition to the Zaire (Congo)

[38] Humphreys and Abbot, op. cit., pp. 97, 98.

[39] M. W. Kingsley, "West African Studies," 2d Ed., London, 1901, p. 87.

[40] H. T. de la Beche, "The Geological Observer," Philadelphia, 1851, p. 370.

as containing the statement that Professor Smith had seen a floating mass about 120 feet long and probably washed out of the Congo, consisting of reeds resembling *Donax* and a species of *Agrostis*, among which branches of a *Justicia* were still growing. Powers[41] saw a floating island in the Gulf Stream in July of 1892. Its area was estimated at about 9,000 square feet and it carried trees, 30 feet high. It was seen again in September, having travelled more than 1,000 nautical miles. This, first seen in latitude 39° 5′, may have been torn off from the Florida coast. In every case the floating islands are of small extent and their rarity makes them objects of curious interest.

Driftwood.—Great rivers carry immense quantities of trees from the undermined banks. Where the course of the stream is interrupted by extensive lakes, such as Great Slave or Athabasca, much of the floating timber becomes scattered and is cast on the shore to be mingled with the mineral material, which eventually buries it. When the stream is continuous, some of the drift is cast ashore in eddies, more is stranded during flood time on the delta or in shallows at the mouth; but by far the greater part is swept out to sea, there to be battered by the waves or carried by currents to perhaps distant shores. Nordenskiold[42] relates that driftwood in the form of small branches, pieces of roots and whole trees with adhering portions of roots and branches, occurs in such quantity at the bottom of two well-protected coves near Port Dickson, that the seafarer may provide a sufficient stock of fuel without difficulty. The great mass of driftwood carried down by the Yenesei floats out to sea. Some of it is drifted by currents to Nova Zembla, the north coast of Asia, Spitzbergen, perhaps to Greenland. Some of it becomes water-soaked and sinks before reaching those shores. But not all goes to sea, for some sinks in the river bed, upright as though rooted in the sands. A bay off Port Dickson was found barred by a palisade of driftwood.

[41] S. Powers, "Floating Islands," *Pop. Sci. Monthly*, Vol. LXXIX., 1911, pp. 303–307.

[42] A. E. Nordenskiold, "The Voyage of the *Vega* around Asia and Europe," New York, 1882, pp. 152–154.

That the amount of driftwood accumulated on shores has been estimated in exaggerated style is amply evident from Brooks's[43] observations. In the north and northwest part of Alaska from Norton bay to the mouth of the Mackenzie river, the shore at one time was abundantly supplied with driftwood. The Eskimos, who have been using this wood for generations, are very economical in the matter of fuel and, until the coming of the white man, the probabilities are that the wood accumulated more rapidly than it was consumed. This driftwood is brought down from the interior by the larger rivers, whose banks are forested. The cutting of wood along the banks of the Yukon has already diminished the contribution to the northern Bering sea. The north Arctic coast, eastward from Point Barrow, which is thinly populated by natives and rarely visited by the white man, has some driftwood, but according to Franklin, the quantity is unimportant along the coast visited by him; the material is brought down by the Mackenzie and is carried eastwardly by a strong current. McClure found driftwood on the northeast coast of Banks land, where it is often at a considerable distance above sea level. Low[44] found that the prevailing winds and the force of the waves have determined the accumulation of driftwood on the shores of Hudson Bay. During great storms, the older, the lighter portions of the mass are thrown to a considerable height above mean tide.

The driftwood deposits on the northern side of Spitzbergen, on Jan Mayen and Iceland are mentioned in most of the current textbooks of geology. Some of them, such as the Suturbrander of Iceland and the deposit on the New Siberia islands are clearly not driftwood, at least not the driftwood under consideration, as they contain fruits and tender portions of plants and belong to the Tertiary. As to the others, of undoubted modern origin, the common conception is simply misconception. The descriptions, in many cases, would lead one to suppose that the mass is closely packed and almost con-

[43] A. H. Brooks, "The Coal Resources of Alaska," Twenty-second Ann. Rep. U. S. Geol. Survey, 1902, Part III., p. 570.

[44] A. P. Low, Ann. Rep. Geol. Surv. Canada, N. S., Vol. III., 1889, p. 33 J.

tinuous. Potonié[45] has given reproductions of two photographs, one from Jan Mayen and the other by Nathorst from Amsterdam island. The drift material is scattered irregularly, as one should expect, with here and there a considerable pile. The fragments, some of which are very large, are thoroughly battered—the whole resembling very closely what one sees on the gravel flats of rivers subject to flood.

Crantz[46] was among the first to describe the driftwood deposits of Greenland and adjacent regions, and his statements have been cited again and again, acquiring the increment which usually comes with frequent repetition. In the driftwood on those shores he saw many great trees, which had been torn out by the roots and which, through driving and dashing amid the ice for many years, had been deprived of bark and branches and had been bored by worms. A small part of this débris consisted of willows, alders and birches from bays in southern Greenland; with these were aspens from some more distant region; but the predominant forms are pine and fir with great abundance of a fine grained wood, with few branches, which he took to be larch. With these is a reddish wood of agreeable odor, resembling the Zirbel of the Alps. The grouping shows that the trees came from a fertile but cool or alpine region.

The drift could not have come from the American coast at the southwest as the current is contrary; it must have come with the icy current. It is most plentiful on the coast of Iceland and, on the southwest side of Jan Mayen in N. L. 75°, there are two bays in which there is so much wood, driven in by the ice, that a ship might be loaded with it. He thinks the wood may have come from Siberia, where pine and cedar abound, though it may have come from the west coast of North America by way of Bering strait.

Crantz may be right or wrong in his suggestion respecting the source of the material; that is unimportant. His description shows that the mass, though considerable, is comparatively insignificant. The accumulation on the Jan Mayen bays, instead of being a closely

[45] H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," Berlin, Funfte Aufl., 1910, p. 126; *Naturwiss.-Wochinschrift,* Vol. IV., Part 4.

[46] D. Crantz, "The History of Greenland," Eng. Trans., London, 1820, Vol. I., pp. 35–37.

packed deposit, was merely enough to load a Danish merchantman of one hundred years ago—say a vessel of 400 or 500 tons. The description shows also that the wood had floated long; it matters not whether it came by the slow drift from Siberia or Norway to northern Greenland and thence southward, or followed the north coast eastward to Davis strait, it is certain that the voyage was very long and the wood showed the effects. This long continued buoyancy of the wood is equally evident in the Gulf of Mexico, where one finds the Mississippi drift wood stranded on the shores along hundreds of miles.

In all extensive deposits of driftwood, the trees are battered, stripped of leaves, bark and often of branches; they are scattered on the strand or piled in irregular loose heaps, where, exposed to the air, they decay; or if in more favorable conditions, the interstices become filled with sediment, the trees become merely logs in shale or sandstone, even their genus being unrecognizable except by microscopic study of the structure.

The quantity of finely divided organic matter transported by rivers is minute in comparison with that of inorganic. Pourtales[47] examined sediment from samples of Mississippi water collected at Carrollton, Louisiana. The first series, taken in March during a flood from the Red and Ohio rivers, yielded no matter of organic origin aside from some spicules of sponges and rare vegetable fibers. A second series, collected in June, during a Missouri flood giving the most abundant sediment of the year, contained in water from the surface some indistinct vegetable fibers and wood cells, but no remains of vegetables were found in the other samples taken at various depths. A third series, in August, contained a vegetable scale or a leaf of moss; while a fourth series, in October, contained no organic matter. A fifth series, collected in the following January, showed on nearly all the filters minute black bodies which may have been pollen or spores.

But the absolute quantity of organic matter carried out is considerable. The "mud lumps" off the mouth of the Mississippi, are masses of tough clay, occasionally forming islands of several acres,

[47] L. F. Pourtales, in Humphreys and Abbot, Appendix 8, p. 651.

which rise 3 to 10 feet above the water and give off much inflammable gas. They were studied by Sidell[48] for the Mississippi survey of 1838 and by Humphreys and Abbot at a later time. Sidell believed that in outflow of the river the finest materials, organic matter and silt, went farthest and, after deposition, were covered with coarser materials. Decomposition of the organic matter generates gas, which lifts the overlying deposits. According to Humphreys and Abbot, the mud lumps are formed on the crests of bars and their activity ceases when the gas is exhausted. In 1858, during operations for removal of obstructions, some mud lumps on the bar of Southwest pass were broken by an explosion of gunpowder. Strong ebullition of gas continued over a wide area for 20 minutes after the explosion and the surface of the bar, in a space, 100 feet diameter, sank, assuming the form of an extinct crater. Hilgard[49] gives as composition of gas from one of the mud lumps, marsh gas, 86.20, carbon dioxide, 9.41, and nitrogen, 4.39, which closely resembles the average composition of gas from swamps. Oxygen is absent.

Very little of the vegetable material is stranded on the banks of rivers, comparatively little is deposited on the deltas. Most of the great accumulations in the Mississippi delta, supposed at one time to be driftwood, have proved to be buried forests in place. Terrace deposits along the Monongahela, in Pennsylvania and West Virginia, contain only here and there a woody fragment in the mass of sand, clay, gravel and blocks of rock. The same is true of terrace deposits generally, away from the lines of abandoned curves. In this connection, Brown's[50] observations along the Amazon are instructive. Long lines of cliffs, now on one side, now on the other, are composed of bright-colored deposits, contrasting with the monotonous clay banks of the river. The elevated plateau of these old river deposits, as well as the alluvial plain, is covered with luxuriant forest. Except a narrow strip along the bank, the whole plain is overflowed

[48] Humphreys and Abbot, op. cit., pp. 485, 486; W. H. Sidell, Ibid., Appendix A, p. 499.

[49] E. W. Hilgard, "The Exceptional Nature of the Mississippi Delta," *Science*, N. S., Vol. XXIV., 1906, p. 865.

[50] C. B. Brown, "On the Ancient River Deposit of the Amazon," *Q. J. Geol. Soc.*, Vol. XXXV., 1879, pp. 763–777.

during the periodical floods. The cliff crests are from 10 to 160 feet above the floodmark and sections show white, yellow and red sands with bluish or variegated clay beds. Ten feet of red clay was seen at the top of one section, while in another are white clays resting on bright red clays. The area studied by Brown is about 400 by 1,000 miles. Within this he saw four insignificant exhibitions of vegetable matter in the deposits, which seem to have been laid down in an estuary.

It is evident that very little of the drifted material is deposited anywhere within the river region or immediately beyond; the driftwood deposits on the northern shores, though vast in the aggregate, clearly represent but a small part of the timber brought down by the great northward flowing rivers; the writer has followed the Gulf Stream for more than 3,000 miles but he has rarely seen floating logs; in the central part of the so-called Sargasso sea of the north Atlantic, he saw no floating timber and captains of steamships familiar with that area have assured him that driftwood is of rare occurrence; the Orinoco brings down great numbers of trees which should be caught by the westward current, but the writer, during two voyages between Trinidad and Colon, saw not one. What, then, becomes of the vegetable material carried down by the rivers?

Deep sea soundings in the Atlantic ocean give no answer to the question. Material brought up by the trawl seems to be practically free from vegetable matter. It has been suggested that the constant "creep" at great depths maintains the supply of oxygen, which under the pressure would be greater than at the surface, so that organic matter would be destroyed. Whether or not the explanation be in this suggestion, it is certain that where different conditions of movement and pressure exist, one finds an accumulation of vegetable material on the ocean bottom. The observations by Agassiz[51] in the Gulf of Mexico and the Caribbean as well as in the Pacific off the coast of Mexico are final in respect to this matter. His statement is that

[51] A. Agassiz, "Three Cruises of the *Blake*," *Bull. Mus. Comp. Zool.*, Vol. XIV., p. 291; "General Sketch of the Expedition of the *Albatross*, 1901," Vol. XXXIII., p. 12.

"While dredging to the leeward of the Caribbean islands, we could not fail to notice the large accumulation of vegetable matter and of land *débris* brought up from deep water many miles from the shore. It was not an uncommon thing to find at a depth of over one thousand fathoms, ten or fifteen miles from land, masses of leaves, pieces of bamboo and sugar cane, dead land shells and other land *débris*, undoubtedly blown out to sea by the prevailing trade winds. We frequently found on the surface masses of vegetation, more or less waterlogged and ready to sink."

The violent hurricanes of the Caribbean, as described by Maury, must contribute very largely to the mass of vegetable material. Agassiz found similar conditions at the bottom of the Pacific during the cruise of the Albatross, when he was surprised at the distance to which land-derived material had been carried. Along most of the distance between Acapulco and the Galapagos islands as well as all along the coast from Acapulco northward to within the Gulf of California, there is a very sticky mud covering the bottom and interfering seriously with the work of dredging. His description of conditions between Acapulco and the Galapagos is

"Nearly everywhere along our second line of exploration, except on face of the Galapagos slope, we trawled along a bottom either muddy or composed of Globigerina ooze, more or less contaminated with terriginous deposits and frequently covered with a great amount of decayed vegetable matter. We scarcely made a trawl which did not bring up a considerable amount of decayed vegetable matter and frequently logs, branches, twigs, seeds, leaves, fruits, much as during our first cruise."

The conditions were similar along the continental coast. The trawl was ordinarily well filled with mud along with the usual supply of decayed vegetable matter. Observations of like character have been made by others elsewhere in the Pacific.

In all probability, a great part of the vegetable matter swept out to sea disappears by oxidation at the surface or in the depths; but in favorable localities another great part is deposited in fragmentary condition with fine muds on the bottom, there eventually to form beds of carbonaceous shale.

Conclusions.—The grouping of facts presented in the preceding pages, proving similarity of conditions in all parts of the world, seems to justify the following conclusions:

1. If torrents carry clear water, they produce little effect on

either the rock over which they flow or the vegetation growing on the floor or on the walls. If they carry sand, clay or even fine gravel, vegetable growth on islands, formed by aggradation, resists the flow and causes increased local deposit without material injury to itself. Even fierce mountain torrents sweeping their load of very coarse materials over a dejection cone do not clear the surface from trees.

2. Water of rainfall has practically no ability to remove a cover of living vegetation, even on steep declivities, except indirectly—as by finding access to unconsolidated material below, which may be rendered semi-fluid, so as to move down as a landslide. The heaviest rainfall barely disturbs the cover of litter in a forest; that material breaks the force of the falling drops, it absorbs much of the water, it obstructs the formation of rivulets and protects itself as well as the underlying soil from erosion. Forests are practically uninjured by the heaviest rainfall; even tiny plants, growing in clefts of rocks are equally undisturbed. Rain does not remove the petty deposit of soil on a projecting point of rock, if a tuft of grass has thrust roots into it.

3. River floods in great lowland areas rise slowly, as is shown by the floods of Mississippi, Amazon, Orinoco, Nile and the rivers of central Africa. In passing through forests, those floods lose speed and become merely a quiet overflow with sluggish movement, so that they disturb neither the living growth nor the decomposed litter on the surface. They move the loose dried twigs and leaves, but even those in great part, are transported only a short distance, unless swept into the stream from the bank. The main current itself cannot uproot trees; it cannot even tear loose a floating tree which has lodged against a sandbar directly in the line of strongest flow; but, unless the sandbar be washed away and the tree be set free, that will remain as a "snag," to become more firmly fixed during each succeeding flood. In most cases, the areas subject to these vast floods are prepared beforehand by heavy rains, whereby the humus cover is soaked and, so to say, cemented to resist the moving water. A dense growth of vegetation forms in the channels of tropical rivers and offers such resistance that even the mightiest

floods are checked as surely as though dammed by a mountain. Logjams are not swept out by the greatest floods, though the accumulation is merely superficial; in spite of floods, they accumulate at the upper end while decaying at the lower. If floating débris enter a lake of moderate size, it finds its way directly to the outlet; but if the lake be large and disturbed by waves, the débris is scattered along the shores. Finely divided organic matter carried out by floods is in minute quantity compared with the mineral matter and it is deposited along with the fine mud.

4. The trees as well as the humus swept out by floods were not uprooted by the running water. Their presence in the current is due to the undermining of banks composed of unconsolidated material, so that trees, humus and the rest fall together into the water to be carried away. The damage thus done is very small—the drift carried by the lower Mississippi being the accumulation from the soft banks of more than 20,000 miles of river, the length of torrential and semi-torrential streams being neglected, as they contribute an insignificant proportion of the mass. The quantity of driftwood in all is unimportant, when one considers the area into which it is swept. Comparatively little lodges on its way down the larger streams and most of that is buried in muds as "towheads" or "snags" or accumulates in rafts to disappear by rotting. A small part is stranded on deltas, far less than has been supposed, for in the Mississippi delta the deposits, supposed to be of driftwood, are now known to be old swamps and forests buried *in situ*. Much finds its way to shores more or less distant where, after having been for long time the plaything of winds and currents, it is cast in battered condition, scattered here in clumps or in individual pieces to decay or to be buried in sands. But the greatest part floats until, in half-rotted condition, after long exposure, it finds its way to the depths of the sea, to litter the bottom in areas, 1,000 to 1,500 fathoms below the surface, where, mingled with remains of marine animals, it will become part of bituminous shales, with here and there a pot of impure coal.

5. The conception that moving water, under any known or recorded conditions, can uproot forests and sweep off peat bogs from

even moderately extensive areas is wholly without basis in fact. One must regard it as originating in medieval descriptions of the devastating force of the Noachic deluge, which became an integral part of religious and romantic literature, so that the conception was accepted as a fundamental truth, needing neither investigation nor proof.

The Phenomena of Peat Deposits.

Peat or turf is familiar to those living in the temperate zone. It is an accumulation of vegetable matter undergoing special chemical change because protected from atmospheric oxygen by an excess of moisture. If one examine an old peat bog, he finds the surface covered by plants of various kinds growing on more or less decayed material. This, in its uppermost portion, is brown or yellowish brown, but the tint deepens downward until in the ripe peat it is almost black. At the top, one finds the vegetable structure distinct, but downward that becomes more and more obscure until in the mature peat it cannot be recognized by the unaided eye, and there seems to be only a vegetable mud containing, at times, fragments of slightly changed wood.

Peat-making Plants.—*Sphagnum* is regarded by many authors as the all-important agent in production of peat; and this supposed condition has been utilized more than once to fortify arguments against the suggestion that coal beds originated from growth *in situ*. The prevalence of this misconception is strange, for evidence to the contrary has been presented in many works during the last century.

Darwin[52] says that in the Chonos archipelago, S. L. 44° to 46°, every piece of level ground is covered with *Astilia pumata* and *Donatia magellanica*, "which by their joint decay compose a thick bed of elastic peat." In Tierra del Fuego, the former is the chief agent. Fresh leaves appear constantly around the growing stem, while the lower ones decay. Tracing a stem downward into the peat, the old leaves can be seen in all stages of decomposition until the whole has become blended into a confused mass. Every plant

[52] C. Darwin, "Journal of Researches," New York, 1846, Vol. II., pp. 24–26.

in the Falkland islands becomes converted into peat. He saw no moss peat anywhere in South America. Thomson[53] notes that peat in the Falkland islands is very different from that of northern Europe, cellular plants being almost wanting. It is formed for the most part of roots, matted foliage and stems of *Empetrum rubrum,* a variety of "crowberry" common on Scottish hills; *Myrtus nummularia,* a creeping myrtle; *Caltha appendiculata,* a dwarf species of water marigold; with some sedges and sedge-like plants. The roots, preserved almost unaltered, may be traced downward in the peat for several feet, but finally all structure is obliterated and the whole is reduced to an amorphous structureless mass. Mrs. Brassey's[54] description of accumulated decayed and decaying vegetation at Borja bay in the Magellan region is in place here, as showing the origin of peat from forest material.

"To penetrate far inland, however, was not so easy, owing to the denseness of the vegetation. Large trees had fallen and rotting where they lay under the influence of the humid atmosphere, had become the birthplace of thousands of other trees, shrubs, mosses and lichens. In fact, in some places, we might be said to be walking on the tops of the trees and first one and then another of the party found his feet slipping through into unknown depths below."

But long prior to Darwin, Al. Brongniart[55] asserted that the presence of *Sphagnum palustre* is not necessary to the formation of peat. One finds on the banks of the Meuse, below Maestricht, some peats containing only leaves of resinous trees. He contents himself with the observation that all are agreed that, for formation of peat, the essential condition is stagnant water, covering the surface constantly and never completely dried up. Lesquereux[56] defined peat as a mass of woody plants whose fermentation and, consequently, decomposition were retarded by the presence and the temperature

[53] C. Wyville Thomson, "The Atlantic," New York, 1878, Vol. II., p. 185.

[54] Mrs. Brassey, "Around the World in the Yacht *Sunbeam*," New York, 1883, p. 128.

[55] Alex. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, Vol. II., p. 41.

[56] L. Lesquereux, "Quelques recherches sur les marais tourbeux," *Mem. Soc. des Sci. Nat. Neuchatel*, Vol. III., 1845, p. 26.

of water. Vogt,[57] while giving pre-eminence to *Sphagnum*, notes that under favorable circumstances any vegetable substance can be converted into peat, for some peats are formed of grasses and reeds. Heer[58] assigns to mosses only a subordinate part and asserts that peat originates partly from mosses, partly from water-plants, from swamp plants, especially from grasses and sedges, and partly from woody plants. A. Winchell in 1860 and Grand'Eury in 1882 made the conditions equally clear, while Früh[59] showed that *Sphagnum* is a late arrival in accumulation of peat.

Peat in the Tropics.—The belief prevails that peat is not produced in the tropics. Jameson,[60] long ago, asserted that peat is peculiar to cold climates, but not wholly so, for Anderson had received some from Sumatra. It is quite natural to find peaty substances in warm climates for peat at the bottom of a mountain is more decomposed than that at the top; that of southern England more than that of north Scotland; that of France is more coaly than that of England, while no peat is found in the French lowlands except under cover. All of which shows that decomposition increases toward warm climates, until, in the tropics, it is so rapid that masses of peat cannot form.

Früh[61] was unwilling to believe that true peat forms in the tropics. He discusses a great number of reported occurrences in tropical and sub-tropical areas. For him, the observations are incomplete and his conclusions are that, so far as known, there is no important deposit of true autochthonous peat in the lowlands of the tropics; that, within the tropics, formation of peat is in elevated regions, where the climate is that of the temperate zone; that the supposed peat layers, bored through in the alluvium of great trop-

[57] C. Vogt, "Lehrbuch der Geologie," 2d Aufl., Braunschweig, 1854, Vol. II., p. 110.

[58] O. Heer, "Die Schieferkohlen von Utznach und Dürnten," Zurich, 1858, pp. 1–4.

[59] J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883.

[60] R. Jameson, "An Outline of the Mineralogy of the Shetland Islands, and of the Island of Arran," Edinburgh, 1798, pp. 151–153.

[61] J. J. Früh und C. Schröter, "Die Moore der Schweiz," Bern, 1904, pp. 134–143.

ical streams, are prevailingly allochthonous. In this last his reference is to the record cited by Lyell,[62] of a boring in the Ganges delta, which passed through a deposit, having certainly the characteristics of a peat bed. In view of what has been said on preceding pages respecting the accumulation of drifted vegetable matter and of the fact, that the great deposits in the Mississippi delta, formerly supposed to be of drifted material, are of *in situ* origin, one is justified in saying that the testimony of that and other borings cannot be waived aside lightly by the mere assertion of allochthony. The onus of proof is on the one making the assertion.

It is difficult to understand why the *a priori* reasoning that tropical heat should prevent peat formation is thought so conclusive as to make worthless the testimony, which would be accepted as proving the presence of peat in Michigan or north Germany. The conditions of temperature during summer in much of the United States are decidedly tropical; yet peat accumulates. It is true that vegetable matter exposed to moist air must decay more rapidly where the temperature is constantly high than in the temperates, where the hot period is of brief duration; but that has nothing to do with the matter under consideration, for one is concerned with decay of vegetable matter protected from atmospheric action by a plentiful cover of water. *A priori*, one should expect to find peat accumulating in those tropical regions, where the conditions are such as encourage peat-making in the temperates—with only the difference that, owing to the continuous high temperature, complete decomposition should be more rapid and the bog should have the vegetable mud near the surface. But one is not dependent on *a priori* reasoning.

Harper[63] notes that it is an error to suppose that peat is confined to cold climates, since high temperature does not prevent its formation if humidity and topography favor. Peat is abundant on the very border of the tropics in Florida, where tropical temperature prevails throughout the year. *Sphagnum* does not occur south from

[62] C. Lyell, "Principles of Geology," Eleventh Ed., New York, 1872, Vol. I., p. 476.

[63] R. M. Harper, "Preliminary Report on the Peat Deposits of Florida," 3d Ann. Rep. State Survey, 1910, pp. 214, 274, 287, 292.

N. L. 29°, but the peat deposits within southern Florida, as far south as lat. 25° 30′, are of great thickness, one dense cypress swamp showing 20 feet. The Everglades of Florida embrace about 7,000 square miles, which must be regarded as considerable. Even between lat. 30° and 31°, there are thick deposits in which *Sphagnum* is wanting or very rare. Cypress, grasses, fern, myrtle make up most of the vegetation and provide material for peat. The water hyacinth, recently introduced into one of the rivers, is now a peat-maker and, in some localities, the peat is composed almost wholly of this plant.

The temperature conditions in the Bermudas are somewhat less severe in summer than in southern Florida, for the summer heat rarely exceeds 84° F. The southwest wind, blowing off the still warm Gulf Stream, prevents low temperature and the humidity is always high. On the main island there are two great swamps, one of which has at least 50 feet of peat. The climate is such that plants of Carboniferous type could grow well, for the banana thrives while palms and the India rubber tree attain great size.

The literature bearing on tropical swamps is very limited. Those swamps, often of vast extent and covered with dense forest, are regarded, rightly or wrongly, as malarial to the last degree, so that they do not invite close examination on the part of travellers. Yet, even in the limited literature, one finds ample proof that, when the necessary condition of topography and continuous moisture prevail, peat does form.

Wall and Sawkins[64] estimate the swamp area of Trinidad at six per cent. The long dry season is not favorable to the accumulation of peaty materials; yet the Nariva swamp, drained by streams flowing 12 to 15 feet below the general level, has a black soil which after desiccation at 300° F. still yielded 35 per cent. of organic matter. Hartt[65] found peat in the state of São Salvador, Brazil, S. L. 10°. He states distinctly that he found peat. "A quarter of a mile south

[64] G. P. Wall and J. G. Sawkins, "Geology of Trinidad," London, 1860, pp. 62, 63.

[65] C. F. Hartt, "Geology and Physical Geology of Brazil," Boston, 1870, pp. 365, 509.

of the Imbuçahí is such a grass-covered area, and here excavations by the side of the railroad show that a bed of peat has accumulated, which is two feet thick in some places." It is difficult to understand on what grounds a recent writer feels justified in asserting that this is probably bituminous shale. Hartt knew peat and he knew bituminous shale when he saw them. On the authority of the engineer who constructed the railroad in São Paulo, Hartt states that near Tumanduathy the land spreads out between the hills, level as a lake and about two miles wide, covered with deep layers of black soil "fibrous and woody like peat." The railroad was built over the surface of this bog, but no effort was made to determine the thickness of the deposit.

Mrs. Agassiz, cited in another connection, gives evidence respecting present conditions in Brazil. Kuntze[66] has described the forested swamps on the divide between the Amazon and the Paraguay. High water makes ponds on the broad alluvial plain, in which *Pontederia* and other plants settle. The ponds become filled with silt and humus and a swamp flora, rich in palms, takes possession of the surface. The Lourenço or Cuyaba river, rising in the low divide, unites with the Paraguay at about S. L. 18°. This river, for about three degrees of latitude, flows through the vast wooded Guatos swamp, which Kuntze thinks is, at least in part, a floating bog. He gives no estimate of thickness, but his brief statement leaves no doubt that the mass is very great. The material is true peat, for in another part of his work he speaks of the fragments of peat occasionally torn off from the mass. The invasion of streams by grasses is rapid and complete throughout this region. Kuntze notes this. Morong,[67] in speaking of his attempt to reach the head of Pilcomayo river in S. L. 22°, says that his progress was stopped in a lagoon, 400 miles from the Paraguay river, by a dense growth of grasses and weeds, one species of the former attaining the height of 5 meters.

The great accumulations in the lowlands of Nicaragua and Costa Rica have been mentioned by several authors and the writer knows

[66] O. Kuntze, "Geogenetische Beiträge," Leipzig, 1895, pp. 5, 67, 70.

[67] T. Morong, *Ann. N. Y. Acad. Sci.*, Vol. VII., 1892, pp. 45, 260.

that great swamps with notable depth of vegetable mud abound on the isthmus of Panama.

Livingstone, Cameron and others, already cited, have given abundant evidence that peaty accumulations are numerous and extensive in the wet regions of interior Africa. Lugard,[68] in describing the region near Albert Edward lake, refers to interminable river swamps and bottomless quagmires, choked with papyrus, which abound in Uganda and Ungoro and cease below about half a degree south from the equator. Miss Kingsley[69] says that she encountered three types of bog in west Africa. The broad deep bog was the least difficult, as it makes a break in the forest, and the sun's heat bakes a crust over it, on which one may go—if he go quickly; the shallow, knee- or waist-deep bog is little more difficult as one can wade through it; but the deep narrow bog, so shaded that the sun cannot form a crust over it, is the most abundant and the most difficult. "These required great care and took up a great deal of time. Whichever of us happened to be at the head of his party, when we struck one of these, used to go down into the black, batter-like ooze and try to find a ford, going on into it until the slime was up to the chin."

Chevalier[70] has described an interesting type of peat formation observed in an extended area between the Gulf of Guinea and the sources of the Niger, N. L. 5° to 9°. This great region has many granitic peaks rising to 1,200 or 1,400 meters, but in great part it is a peneplain, 200 to 400 meters above sea level. The southern portion is covered with a dense forest but the northern portion is a savannah with only scattered trees and shrubs. The whole region would be naked rock, were it not for the rôle played by a sedge, *Eriospora pilosa* Benth., which at times covers the rocks to the exclusion of all other forms. It attaches itself to granite and gneiss; the seeds germinate in minute fissures and the roots spread in clusters between thin plates of the rock, altered or decomposed by atmospheric action. When the thin plate of rock has been worn away

[68] F. D. Lugard, *Scottish Geog. Mag.*, Vol. VIII., 1892, pp. 636–639.

[69] M. W. Kingsley, "Travels on the Western Coast of Equatorial Africa," *Scott. Geog. Mag.*, Vol. XII., 1896, pp. 119–120.

[70] A. Chevalier, "Les tourbières de rocher de l'Afrique tropicale," *C. R.*, Vol. 149, 1909, pp. 134–136.

by water, heat or the activity of the plant, this is ready to resist the rains and winds, for its adhesion is complete on the steepest slopes.

After spreading for sometime, the *Eriospora* lifts its rhizomas into the air and sets off branches, each terminated by a bouquet of grass-like leaves, and each year, before the rains, abundant rosettes of leaves and flowering twigs are developed at the end of these rhizomas. At the beginning of the dry season, these leaves wither and soon afterward they are consumed by fires lighted by men or perhaps by lightning; only the bases of the leaves remain; blackened, half-carbonized, this coat thickens around the rhizoma. The growth of the *Eriospora* tufts is apparently very slow, but, as they may live for several centuries, they attain notable dimensions. On the border of the virgin forest, some were seen more than a meter high and half a meter thick at the base. The stem divides midway into vertical branches, themselves dividing, the last division having a diameter of 2 to 3 centimeters.

The tufts are not always in contact, there being at times an interval of even 50 meters, but in these intervals on gentle slopes, one finds a fibrous network, very humic, constituting a veritable bed of peat, 5 to 30 centimeters thick. This peat is formed not only of roots and rhizomas, but also of young colonies of *Eriospora*, killed soon after origin by fire or by lack of light. True mosses appear at high altitudes. On the humid flank of Mount Momry, Chevalier found a *Sphagnum* at 850 to 900 meters above sea level. The *Eriospora* peat covers tens of thousands of hectares in French west Africa. The condition described by Chevalier is not wholly unfamiliar in the temperates, where mosses and other plants cover irregular rocky surfaces and form a coating of peat at times several inches thick. This is seen frequently in the southern Appalachians. It is the Rohhumus or Trockentorf of the Germans.

It was reserved for Potonié[71] to present the final evidence. Finding no available literature giving details respecting moorformation in the tropics, he applied to Koordes, botanist of the Dutch expedition across Sumatra in 1891. Koordes informed him that in old

[71] H. Potonié, "Die Entstehung der Steinkohle und der Kaustobiolithe überhaupt," 5th Aufl., Berlin, 1910, pp. 152–160.

Javan and Sumatran forests, where hard woods grow, fallen trees, many decades old, lie in great numbers and are still in good condition for export. Termites and fungi are effective agents for destruction of wood in the tropics, but the moisture is almost equally effective in preventing the decay. During the Sumatra expedition, Koordes saw a great, always green Flachmoor, with a 30-meters high mixed forest, extending along the Kampar river at more than 90 kilometers from the coast. As Koordes had made no close study, definitive evidence was wanting to prove that this moor had a true peat floor. But Larive made the necessary sounding at Potonié's request and discovered that the peat in this tropical moor is 9 meters thick.

Examination with the microscope proved the presence of phenogams; spores or pollen; occasional brown threads belonging possibly to fungi; some resin-like bodies, etc. The high content of silica in the ash explains absence of diatoms in the microscopic preparations. Chemically, the material is a true peat and German experts pronounced it a good fuel. The ash in the dry material is 6.39 per cent. while good north German Flachmoor peat has 5 to 7 per cent. The ash of the Sumatran peat contains 74 per cent. of silica.

Koordes estimated the area of the freshwater swamp on the left bank of the Kampar at 80,000 hectares. At both camps within this swamp, the water was stagnant, dark brown and slightly astringent. Walking over the swamp was possible only because roots of trees covered the surface with a dense network. The character of the growth, as shown in Fig. 52 of Potonié's work, is a clear instance of adaptation such as is seen in the *Taxodium* of the southern United States; for the roots are widespread horizontally just below the surface, uniting into "broom-shaped air roots" and "asparagus-shaped pneumatophores." The trees of the forest are mostly evergreens, 25 to 30 meters high and closely set. The underbrush consists, for the most part, of the same species but its growth is slow, owing to the dense shade. The forms are all dicotyledonous and the flora is wholly of inland type. Grasses, sedges and mosses are practically wanting; it is a forest moor. The stagnant pools, poor in phenogams because of the dense shade, are comparatively rich in confervae.

It is sufficiently evident that there is nothing in tropical conditions which would prevent the accumulation of peat. Where there is a long dry season, the vegetable matter is exposed as is that in the ordinary upland forest in the temperate regions. The accumulation of the humus cover advances rapidly for a time but at length the waste by oxidation about balances the additions, so that the thickness does not increase, though the trees shed a greater quantity each year. But in a lowland area where the moisture is great, the chemical changes are modified, the loss is diminished and increased supply brings about increased accumulation. Swamps arise, when from any cause the drainage is impeded. Even along the flow of small springs, peat forms when the water is held back from any cause. On extensive areas, such as the coastal plain on the Atlantic side of the United States or the delta of a river like the Mississippi, where at best the drainage is imperfect, the streams being sluggish and often serpentine, the drainage has been hindered still further by vegetation, the moist area was enlarged and swamps of vast extent originated in post-glacial times. The important condition is the constant supply of water; the drainage must be impeded on the surface and through the bed. In the northern part of the United States probably the greater part of the swamps rest on an impervious bed of glacial clay, an underclay; but it is not necessary that the immediately underlying bed be of normally impervious material, for many large swamps have a floor of fine sand.

Harper[72] penetrated 10 or 12 miles into the Okefinokee swamp of southern Georgia and discovered that the material on which the peat rests is a few feet of Columbia sand overlying the clay, loam or coarse sand of the Grand Gulf formation (Lower Miocene or Upper Oligocene). In some places a "hard pan," colored by vegetable matter and cemented by iron underlies the sand. Sanford[73]

[72] R. M. Harper, "Okefinokee Swamp," *Pop. Sci. Month.*, Vol. LXXIV., 1909, p. 596.

[73] S. Sanford, "Topography and Geology of Southern Florida," 2d Ann. Rep. Geol. Survey of Florida, 1909, p. 193.

reports that the peat of the Everglades in southern Florida rests on sand, rock or marl. Grisebach, cited by Früh, endeavored to explain this apparently anomalous condition for north Germany by the suggestion, that, in very wet years, peat may have been formed in that region even on sands and, being itself practically impermeable, it may have prepared the way for a Hochmoor. Be that as it may, the fact remains that a swamp may begin on an apparently permeable surface; the Everglades are at little above sea level, but Okefinokee is 50 miles from the ocean and 115 feet above mean tide—and its mucky peat contains 85 per cent. of combustible material. In this latter case, one must believe that the underlying sand is not far from an impermeable stratum and that it is saturated with moisture or that by absorption of humic acid the sand itself has been rendered impermeable.

Peat and Peaty Materials.—Russell[74] describes the Alaskan tundra as a swampy, moderately level country having a cover of mosses and lichens with some ferns and many small flowering plants. Below this dense carpet of vegetation is dark humus. Ponds and lakelets abound, surrounded by banks of moss, and occasionally one finds groves of alders and dwarf willows on their borders. The underlying black humus shows few indications of its vegetable origin. It is 2 feet thick at St. Michaels but is 12 feet at a mile farther east. He saw 15 feet on the Yukon and a depth of 150 to 300 feet is assigned to it at the head of Kotzebue sound. The flora of the tundra is essentially cryptogamic, but two species of *Equisetum* flourish with rank luxuriance in great spaces along the Yukon. So vast is this accumulation, in both area and thickness, that Russell ventures to suggest that some coal seams may have had similar origin. If the tundra coast of Alaska should subside, its peat would be covered with sediments and be ready for transformation into lignite or coal. Its associated plants and animals would indicate the climatic conditions, but the overlying sandstone and shale might contain leaves and tree trunks, floated in by rivers from warmer regions.

But where the swamp is forested, especially if the wood resist

[74] I. C. Russell, "Notes on the Surface Geology of Alaska," *Bull. Geol. Soc. Amer.*, Vol. I., 1890, pp. 125–128.

rapid decay, the change of that material may advance so slowly that long after the softer parts have been reduced to pulp, the more compact materials may remain almost unchanged. The white cedar logs in the New Jersey swamps are so well preserved in many localities as to be serviceable in manufactures, while the thick peat of many swamps in Florida is without commercial value, because it is crowded with cypress stumps and fallen stems. But decay occurs in the softer woods, so that, as v. Gümbel[75] relates, flattened trunks are found even at a depth of only a meter in loose peat. The flattening was due to rotting, not to pressure.

The newer peat shows distinct felting and Lesquereux[76] states that this condition is marked even when decomposition is far advanced. In peats formed above the original water-plane, the "emerged peats" of that author, the layers are characteristic, one inch thick at the top but decreasing downward to less than one eighth of an inch. While the older or ripe peat shows no trace of organic structure to the unaided eye, the microscope proves that it is composed of fragments of plants embedded in an amorphous material consisting of humic or ulmic acid, or a mixture of those acids and their salts. He observed that, whenever the growth of the peat was checked by dryness or other causes,

"the upper surface of the peat becomes crusted, hardened and transformed into a thin coating, quite impervious to the entrance of any kind of foreign matter: and it is upon this hard upper crust that the boggy humus forms; or wherever the land becomes resubmerged, a new peat vegetation begins. In which case, such a crust remains as a parting layer between two beds of peat, like the well known clay partings between two coal benches."

v. Gümbel, in the work just cited, asserts that the minute fragments of plants are not only intimately mingled and felted but also, in the denser portions, are bound together and more or less cemented by a humus-like substance, which is soluble in a dilute solution of caustic potash. Peat, treated with this reagent and afterwards dried,

[75] C. W. v. Gümbel, "Beiträge zur Kenntniss der Texturverhaltnisse der Mineralkohlen," *Sitz. Berich. d. k. bayer. Akad. d. Wissenschaften. Math-Phys. Kl.*, 1883, p. 126.

[76] L. Lesquereux, 2d Geol. Surv. of Pennsylvania, Ann. Rep. for 1885, p. 118.

frequently falls to powder. v. Gümbel found also, in many peats, deep black coaly parts of plants as small fibers, a form which he terms Torffaserkohle and regards as a thoroughly characteristic type.

Peat always contains much water, often 95 per cent., when freshly removed; but a great part of this evaporates on exposure, there remaining in the air-dried material from 10 to 30 per cent., the denser peat retaining the larger quantity. When first taken out, it is plastic but after thorough drying the plasticity is lost. Peat is very porous; v. Gümbel subjected *Sphagnum* peat to a vertical pressure of 6,000 atmospheres and reduced 100 centimeters to 17.7. The compressed material was apparently homogeneous, the streak was lustrous and lamination was distinct on the fractured surface. The reduction was due wholly to compression, obliteration of the pores, for, when moistened with water, the mass swelled to practically the original bulk. This condition, however, may not be constant. The writer has some briquetted peat, made under great pressure and moderate temperature, which has no tendency to swell when moistened. It has lost all plasticity and in sixteen years it has shown no change on the brilliant surface at each end.

Peat, then, consists, aside from introduced sand, clay or calcareous materials, of more or less changed plant tissues, whose organic texture is still recognizable, and of an enclosing substance derived from complete decomposition of plant tissues, which is originally soluble in water but which, on drying or perhaps on oxidation, becomes insoluble.

Fuel peat has from 1 to 25 per cent. of ash. The purest peats contain less mineral matter than is found in the plants whence they are derived; while on the other hand a peat deposit may pass from pure peat into carbonaceous mud and thence into muds almost wholly without trace of carbon. Mills and Rowan[77] have given ultimate analyses of surface and dense peats from two localities in Ireland, which represent the extremes of high grade fuel.

In each case, the ash is excluded in calculating the other constituents. The same authors give twenty-seven analyses of the ash found in

[77] E. J. Mills and F. J. Rowan, "Chemical Technology," Philadelphia, 1889, pp. 15–20.

different fuel peats from Ireland, which show, as one should expect, extreme variations, due to local conditions. Potash and soda are in small proportion, varying from 0.146 to 1.667 of potash and from 0.446 to 2.883 of soda, the greater quantity being in the dense peat. Phosphoric acid is present in all but rarely exceeds 2 per cent., whereas sulphuric acid varies from 10 to 44 per cent. Hydrochloric acid is present in small proportion, but approximately that required by the soda. Lime and magnesia are always present, in some cases the former makes up nearly one half of the ash and in others the latter is one sixth. Ferric oxide varies from 6 to 30 per cent. Silica occurs as sand or as soluble silica and alumina is always present, though at times in small quantity. The ash in the samples analyzed varies from 1.120 to 7.898.

	C.	H.	O.	N.	Ash.
1. Surface, Phillipstown	58.69	6.97	32.88	1.41	1.99
2. Surface, Wood of Allen ..	59.92	6.61	32.20	1.25	2.74
3. Dense, Phillipstown	60.47	6.09	32.54	0.88	3.30
4. Dense, Wood of Allen	61.02	5.77	32.40	0.80	7.89

The content of alkalies rarely exceeds 4 per cent. of the ash in New Jersey peats and ordinarily it is less than one and a half per cent.; but calcium carbonate and sulphate are always present in notable quantity, making up from 20 to 30 per cent. of the ash.[78]

Julien[79] has given a synopsis of the available information respecting the proximate composition of peat. The various organic constituents seem to be of rather indefinite character and their study is attended with serious difficulty. Julien cites an analysis from Hermann, giving composition of a peat obtained near Moscow:

Muck-carbon, nitrolin, plant remains	77.8
Humic acid	17.0
Humus extract	4.0
Ammonia	0.25
Crenic acids	Trace
Ash	1.25

[78] W. E. McCourt, "A Report on the Peat Deposits of Northern New Jersey," Ann. Rep. Geol. Surv. of New Jersey for 1905, p. 227.

[79] A. A. Julien, "On the Geological Action of the Humus Acids," *Proc. A. A. A. S. for 1879,* pp. 314–324, 329, 331, 353.

But in peat from another locality, the process of change was different:

Muck-carbon, etc.	80.0
Apocrenic acids	17.0
Crenic acids	1.0
Ash	2.0

Julien notes the difference in ash between peat and the plants whence it is derived. *Sphagnum* has from 3 to 4 per cent. and the peat varies from 1 to 25 per cent. Vohl found only 1.25 per cent. of ash in a Hochmoor or *Sphagnum* peat. In the ash of living plants he found 20 per cent. of alkalies and 42 per cent. of silica, but only 3 to 4 per cent. of each in the peat or in the soil. On the other hand, there was concentration of alumina, ferric oxide and calcium carbonate as well as of phosphoric and sulphuric acids. Pyrite occasionally abounds in peat and its decomposition gives a basic ferric sulphate to the bog iron ores.

Nitrogen is always present in peat, sometimes as much as 3 per cent. Many suggestions have been made to explain its occurrence; but Julien thinks that most probably it has been derived from animals living in the peat or in the soil. The vast number of insect cases found in peat bogs is well known and Scudder has proved that insects were very abundant in the coal period. The nitrogen content is due very largely to the exuviæ of insects, and its frequent concentration in the lower layers of bogs may be due to the survival of those exuviæ as chitin.

In the humus one finds as inert substances, nitrolin (rotten wood) and humin, which is black and forms the chief constituent of humus; but it is so mingled with nitrolin that its exact composition cannot be determined. Mulder studied humus and humic acid from the black peat of the Haarlem sea; he obtained ulmic acid from rotten wood as well as from the light brown Frisian peat. The formulas of the several acids obtained seemed to be

Humic acid	$C_{20}H_{12}O_6$
Geic acid	$C_{20}H_{12}O_7$
Ulmic acid	$C_{20}H_{14}O_6$

Stern, however, thought humic and ulmic acids isomeric, with the formula $C_{24}H_{18}O_9$, while Ditmer thought them the same thing, the latter being produced by drying the former.

Humic acid is a colloid and is not absorbed by plants, though its oxidized product, crenic acid, seems to be taken up. Humic acid is very slightly soluble in water at 6° C.; if dried at 120° C. it is much less soluble and if completely dried at a high temperature it is insoluble. Its alkaline salts are readily soluble but those with alkaline earths and metallic oxides are insoluble or nearly so in water, though readily in aqueous alkaline solutions. Calcium humate dissolves in 3,125 parts of water and ferric humate in 5,000 parts, but these form soluble double salts with ammonia. Ulmic and humic acids are rarely free except in bogs. A noteworthy property of humic acid is that, as a colloid, it renders sand impermeable to water.

These feeble acids yield others upon oxidation. Humic gives crenic, which is present in all waters, in rotten wood, in peat and in cultivated soil. Julien has found it, as well as its oxidized product, apocrenic, in American peat. Crenic acid, pale yellow and transparent, is readily soluble in water; in drying, it becomes opaque and blackens when exposed to the light. Alkaline crenates are very soluble but the calcareous salts are only slightly soluble. Those of iron and aluminium are insoluble, but, according to Bischoff, the iron salt is soluble in ammonia, so that it may be dissolved in the presence of decaying nitrogenous substances. The apocrenates have same distribution as the crenates but they are less soluble. These organic acids bleach clays and have solvent effect on silica; the most efficient being the brown or ulmic constituents.

Liebig,[80] writing soon after Mulder published the results of his investigations, stated that a solution of caustic potash blackens in contact with vegetable mould. Dilute sulphuric acid precipitates from the solution a light, flocculent brown or black substance which absorbs oxygen rapidly. After drying it is not soluble in water. Cold water dissolves only one ten-thousandth of its weight from vegetable mould and the dissolved material is chiefly salts; but boiling water extracts several substances, yellow or yellow-brown. On

[80] J. Liebig, "Chemistry in its Application to Agriculture and Physiology," Philadelphia, 1843, pp. 112, 113.

exposure, the solution becomes darker and a flocculent deposit is produced. If the yellowish solution be evaporated to dryness and the residue be heated to redness, this becomes black and, when treated with water, yields potassium carbonate. Evidently, boiling water extracts a substance which owes its solubility to alkaline salts contained in plants. Leibig says, on authority of Sprengel, that humic acid becomes insoluble when dried in air or when frozen in moist condition.

Hunt[81] has remarked that organic matters in solution acting on insoluble peroxide of iron form the protoxide, which is soluble in carbonic acid and in excess of the organic (acid) matter. In this way, great quantities of iron may be removed and white clay or sandstone may be produced. The iron salts become oxidized and go down as hydrated peroxide. Manganese deposits are formed in similar fashion. He is inclined to believe that hydrated alumina may originate in the same way. Organic matter dissolved by surface waters reduces sulphates to sulphides and these, decomposed in turn by carbonic acid, yield alkaline and earthy carbonates as well as hydrogen sulphide.

One finds in bogs some types of peat to which the descriptions thus far given do not apply. Examined in detail, these in some cases suggest original differences due to mode of accumulation or to character of material, while in others they appear to be due to secondary processes.

Long ago, Caspary described the Lebertorf obtained at Purpesseln, near Gumbinnen in east Prussia. This material was studied very carefully by v. Gümbel,[82] his specimens being from the type locality. The deposit is 5 feet thick and at 10 feet below the surface. When damp, it is liver-brown in color and dense, but when dry it divides into paper-like laminæ. Under the microscope it proves to be composed of very fragmentary parts of plants within a felt-like, flocky mass, in which are insects, recognizable grass and moss, scattered black wood cells, many spores and an immense quan-

[81] T. Sterry Hunt, "Chemical and Geological Essays," Boston, 1875, pp. 97–99.

[82] C. W. v. Gümbel, *op. cit.*, pp. 131, 132, 133.

tity of pollen. Two specimens from other localities agree in that the cross-section shows a comparatively dense mass of boghead-like material, deep brown in color. One contains well preserved remains of leaves and other organs and the other contains some freshwater mollusks. The granular, felt-like mass, treated with reagents, breaks up and then one sees fragments of woody material, seeds, mosses, and above all pollen grains, several thousands to the cubic millimeter. This substance bears remarkable resemblance to cannel.

Blattertorf, so named from its foliated structure, is closely allied to Lebertorf. v. Gümbel has described a specimen from the kurishen lowland south from Nidden. This mass, in extraordinarily thin laminæ, is composed of numerous bright lamellae alternating with dull layers, recalling by their luster, pitch and glance coals. The bright material comes from ribs and the harder parts of plants, the grass leaves, which compose the chief mass. Along with those are bits of moss, bast fibers, etc., in the felt-like mass, as well as an astonishing number of pollen granules.

The results of Früh's[83] studies were published in the same year with those of v. Gümbel. His conclusions respecting the composition of Lebertorf differ somewhat from those reached by v. Gümbel. One rarely finds in ordinary peat any remains of freshwater algæ. But Früh finds that those algæ do not decompose so readily as one might imagine; yet in the ordinary peat they are only rare and accessory constituents, never occurring in such quantity as to be important elements. At the same time there are types of which they are essential constituents.

The Lebertorf, found in ponds within Prussia, as the basis of the Rasenmoor at Purpesseln and as basis of a Hochmoor at Gumbinnen, is a liver-brown gelatinous mass. That from Jakobau, in west Prussia, consists chiefly of algæ, there being more than 60 species of Chroococcaceæ, Hydrodicteæ and Diatomaceæ, with which are found indefinite remains of mosses along with pollen of *Pinus* and *Corylus*. The Torfschiefer of E. Geinitz from Gustrow has a very similar composition. The typical Lebertorf from Purpesseln has recognizable colonies of Macrocystis, while that from Niederwyl

[83] J. J. Früh, "Ueber Torf und Dopplerit," Trogen, 1883, p. 20.

in Thurgau shows algæ as the chief constituents, with pollen and chitin remains, all felted and embedded in a gelatin-like mass. These Lebertorfs originated in quiet waters or on damp soil, through continuous deposition of gelatinous algæ.

Lebertorf is the same with Faulschlamm or Sapropel of Potonié,[84] an accumulation of stagnant water organisms, animals as well as plants, a formation characteristic of pools in swamps. The fresh-water algæ multiply with such rapidity that eventually a great mass may be deposited. Potonié says that there are lakes in south Germany so filled with Sapropel that they cannot be navigated. Caspary, cited by Früh, conceives that there is no peat-filled lake, on whose bottom this material does not exist. He found it about 9 meters thick at one locality. Früh has given a synopsis in his later work of studies by the students of northern Europe which show the wide distribution of this material. But Lebertorf or Sapropel, so closely resembling cannel in appearance, is not the mass of peat; it is wholly local, originating in open ponds or lakes. The gelatinous algæ are of comparatively rare occurrence in true peat, which owes its origin to plants of wholly different type.

The substance, known as Dopplerite, was described by Haidinger in 1851 and was studied in great detail by v. Gümbel in 1858. Its similarity, in some respects, to coal led the latter author to give it the name of Torfpechkohle. It occurs at many localities, so many that it may be regarded as a normal constituent of peat. The first reference to material of this type in America is in a paper by Fairchild,[85] who obtained some from a bog at Scranton, Pennsylvania. It is described as bright, resembling a firm but brittle jelly and as occurring in branching masses through the ripe or older peat. In drying, it shrinks more than the peat and the color changes from yellowish brown to almost black, finally becoming brown. In structure it resembles coal.

Julien,[86] discussing Fairchild's communication, asserted that the physical features of the substance, as described, are those of apo-

[84] H. Potonié, "Die Entstehung," etc., p. 20.

[85] H. L. Fairchild, *Trans. N. Y. Acad. Sci.*, Vol. I., 1881, p. 73.

[86] A. A. Julien, *Trans. N. Y. Acad. Sci.*, Vol. I., 1881, pp. 75, 76.

crenic, humic and other organic acids. He was inclined to believe that this material had been produced by the leaching out of soluble salts of organic acids, in part crenates, from the upper part of the bog and their concentration in the denser portions below, where they filled cavities in the peat. The rapid change in color is not the trifling change due to drying, but is a characteristic reaction of crenic acid, due to oxidation and to partial change into apocrenic acid—a feature observed in the acid and in its salts, both in nature and in the laboratory.

Lewis[87] described the material with more detail. It occurred in swamp muck underlying 8 to 10 feet of peat. Near the bottom and confined wholly to the muck, are irregular veins filled with a black jelly-like elastic substance, in quantity varying from mere stains to streaks, two or three inches wide. When first taken out it is jelly-like, with conchoidal fracture, but on exposure it becomes tougher and more elastic. Under the glass it is brownish red and nearly homogeneous. It is tasteless and odorless, burning slowly and without flame, when fresh. It is insoluble in water, alcohol and ether but is dissolved by caustic potash. Completely dried, it is brittle and coal-like, resembling jet; it burns with a clear yellow flame and no longer softens in water. In composition, it differs from the typical dopplerite in that it contains little more than half as much carbon and very much more oxygen.

Kaufmann, cited by Lewis, regarded dopplerite as a mixture of humus acids and believed that the portion of peat, soluble in caustic potash, is identical with dopplerite. Compact peat contains minute black particles of dopplerite. Peat is merely a mixture of partly decomposed plants with dopplerite, the latter being a homogeneous peat in which all organisms have been decomposed. Kaufmann found that the proportion of material soluble in caustic potash increases with age, a recent peat giving from 25 to 30 per cent., while an old compact peat gave 77 per cent. But in coals, the proportion decreases, from a diluvial brown coal, with 77 per cent., to anthracite in which no portion is soluble. His conception is that, in the forma-

[87] H. C. Lewis, "On a New Substance Resembling Dopplerite, from a Peat Bog at Scranton," *Proc. Amer. Phil. Soc.*, Vol. XX., 1881, p. 112.

tion of coal from peat, the first step is the formation of dopplerite and the second is a gradual transformation of the latter into a material less soluble in alkalies and richer in carbon. The peculiarities of the Scranton mineral, its low percentage of carbon and its mode of combustion led Lewis to suggest that it may represent an earlier stage in transformation than that of dopplerite.

v. Gümbel,[88] in giving the results of his later studies, described dopplerite as a yellow brown homogeneous mass without trace of organic structure and enclosing only separated parts of plants. It burns with a sooty flame, thus differing from the Scranton mineral which burns with a clear flame. It dissolves in acid with effervescence; the calcareous matter seems to be combined chemically with the humus-like material. He is inclined to see in dopplerite a substance originating in mere segregation from plant material as the silica of flints is separated from limestone. He looks upon dopplerite as possessing great importance, since in most peats, one finds cementing substances which, optically, physically and chemically, resemble it closely.

Früh,[89] in his earlier work, already cited, gives an elaborate discussion and reaches conclusions differing very much in some respects from those just given. He asserts that dopplerite exhibits the wholesale formation of ulmin compounds and gives detailed description of its physical and chemical properties to prove that it belongs to the ulmin group. Owing to the large proportion of calcium, he thinks the material pre-eminently a Rasenmoor deposit. On wholly fresh profiles of Rasenmoor at Gonten, Schwantenau and Rothenthurm, he saw in the red-brown peat, brown flakes, one centimeter to one decimeter, so mottling the mass that he termed this type Marmortorf. Very frequently the flakes are associated with a fragment of root or twig, along which water would flow. At Rothenthurm he found the dopplerite first along a root. These brown flocks are always rich in water; the Rasenmoor is always rich in water, a condition which favors homogeneous ulminification of the

[88] v. Gümbel, *op. cit.*, pp. 129, 130.

[89] J. J. Früh, *op. cit.*, pp. 64, 68, 69–72.

peat. The brown flocks are sources of dopplerite. There is no sharp separation between dopplerite and the surrounding peat—there is always a passage zone, an intermingling of peat and dopplerite.

The mode of occurrence is variable. In many places, he saw veinlets, one to two meters long and one to five centimeters wide; here and there a vein spreads out from a root—one passed over a thin sandstone and was prolonged horizontally for several meters as a little bed, at most two centimeters thick. At the same place, he observed some wedge-shaped veinlets penetrating the glacial drift to a depth of 3 to 4 centimeters, where it filled cracks in the clay, binding the fragments into a breccia. There were no plant remains in the clay, so that the fine gelatinous dopplerite must have been deposited in already existing cavities. The presence of abundant water being essential to the ulminification, the mineral is found especially in the lower part of the peat. As every plant can become ulminified, dopplerite may occur in any moor, where the temperature and moisture are in proper relation. He has found the mineral derived from *Sphagnum* at the contact between Rasenmoor and Hochmoor, where the water-rich condition existed.

Kaufmann believed that with the point of a knife he separated particles of dopplerite from good peat; Früh did this with Marmortorf, but he thinks that even the best Rasenmoortorfs are not usually so far advanced as that. The microscope detects little flakes produced by the flowing together of very tender ulmin material, if the peat be ripe; but one cannot determine whether these are ulmic or humic acid—the quantity is too small. At the same time, he maintains that it is an error to identify with dopplerite the caustic potash extract from peat, as Kaufmann and Muhlberg have done, for potash combines with ulmic and humic acid alike. Dopplerite is a higher member of the ulmin group.

Kinahan[90] often observed that, when peat was taken out on the hills near Dingle bay, little streams of tar, which had filled tubes made by decay of roots, oozed and trickled out from the newly made

[90] G. H. Kinahan, Geol. Surv. of Ireland, Explan. of sheets 182, 183, 190, 1861, p. 33.

surfaces. This is clearly the younger stage of dopplerite referred to by Früh.

The Schieferkohle, studied in detail by both v. Gümbel and Früh, is a Quaternary deposit observed at several places in Switzerland. It will be described on a succeeding page. v. Gümbel's[91] type specimens come from Morschwyl, but he studied also specimens from other localities. The mass is partly loose, like peat, partly dense, like pitch coal, containing remains of conifers, birches, etc. It is undeniably peat-like in the less dense portions, where one can recognize mosses and grasses as the predominating constituents. The denser portions are changed by caustic potash into an opaque mass. The microscope shows great quantity of deep brown shell-like splinters of an amorphous textureless substance, which acts as dopplerite. In many parts of plants, the same dark brown material fills the cell spaces. He thinks it not doubtful that the denser condition of this portion of the coal comes from richer accumulation of the amorphous filling material, which he terms Carbohumin. This Schieferkohle contains vast numbers of pine cones, not deformed, and of flattened pieces of wood. In many of the latter, he found an inner woody zone, composed of a soft yellow substance, like rotten wood, while the bark zone had been changed into a shining pitch coal.

Früh,[92] after studying Schieferkohle from many localities, confirmed the view of Heer, Kaufmann and others that the deposits agree with peat in microscopic character. They are peats more strongly ulminified. He often found the interior of rootlets apparently little changed, but after a few minutes exposure, they began to change and at length became brown like the Marmortorf. With regard to the wood fragments, he thinks that the outer portion was ulminified early, perhaps before the bog was covered with drift, whereas the inner portion was merely peated. At the same time he does not recognize dopplerite in the Schieferkohle.

It is sufficiently evident that the difference between Früh and the other observers is merely respecting nomenclature. There is agreement on all matters which concern the questions at issue here.

[91] v. Gümbel, *op. cit.*, pp. 136, 137.

[92] J. J. Früh, *op. cit.*, pp. 83, 84.

This is placed beyond doubt in his later work,[93] where he modifies the broad statements made in his earlier work and shows that the difference is formal rather than real. He says that dopplerite originates, as does the peat, out of a varying mass of colloid substances, free humus acids, salts of humus acids, inorganic substances and some nitrogen. So one may regard dopplerite as an ulmate, a humate, a crenate or a mixture of them all, with in addition some inorganic salts. The essential point is that, during the process of peat-making, a greater or less portion of the vegetable material is brought into a condition admitting of flowage, so that it may remain distributed throughout the mass or may be collected into cavities. When the pores of the peat are filled, farther drainage is possible only to a limited degree and the material will find its way to the tissues, becoming the Carbohumin of v. Gümbel. To this absorption of Carbohumin is due the different effect of pressure upon peat and brown coal; in peat the porosity is very great, in brown coal it is small.

Variations in structure or appearance of the peat have been observed in recent bogs, which are as notable as those found in the Schieferkohle. Griffith[94] in describing the Irish peat bogs, said that bases of the bogs consist of clay covered with a layer of peat, which is composed of rushes and flags. Above this is another bed of peat, closely resembling cannel coal, with conchoidal fracture and hard enough to be worked into snuffboxes. It yields 25 per cent. of ash and much oxide of iron. This, in turn, is covered with black peat containing twigs and branches of fir or pine, oak, yew and hazel, only the bark remaining. Where whole trees were found, the roots had disappeared.

Lesquereux[95] relates that on the border of the valley of the Locle, a considerable mass of marl covers a bed of peat, which has become converted into lignite, hard, fragile and with brilliant fracture. The thickness on the border is barely 3 inches. Farther downward toward the bottom of the valley, the marl is only 4 feet

[93] J. J. Früh, in "Die Moore der Schweiz," 1904, pp. 164, 165, 166, 167.

[94] Griffith, cited by S. S. Haldeman in Introduction to 2d Ed. of R. C. Taylor's "Statistics of Coal," Philadelphia, 1855, p. 166.

[95] L. Lesquereux, "Quelques recherches sur les marais tourbeux," Neuchatel, 1845, p. 95.

thick and the underlying peat, though showing some change, still retains its peaty character and is a passage from the lignite of the border to the peat now worked in the open valley. One is left to conclude that the deposit is continuous from the border to the uncovered peat.

The Characteristics of Peat Accumulations.—Swamp or marsh accumulations of vegetable matter consist essentially of remains of land plants, including the many water-loving types. Locally, as in the Lebertorfs or Sapropels, one finds freshwater algæ and remains of mollusks, while in many swamp peats the exuviæ of insects abound, often associated with land mollusks. Some of the older books refer to marine peat. Macculloch[96] mentioned a peat found in Scotland, which was composed of *Zostera marina,* and several authors have cited this as a marine peat. But *Zostera* is the ordinary "eel-grass" of estuaries and is a land plant able to endure salt water. Al. Brongniart,[97] under the title "Tourbe marine," states that De Candolle saw in the dunes of Holland some peats which burn well and are composed of seaweeds, notably of *Fucus digitatus.* He, himself, had seen, opposite the rock of Calvados, some extensive beds of brown material, soft and spongy, which had all the external appearance of peat, but it could be burned only with difficulty. That seaweeds may accumulate on a strand, there to form a considerable deposit, is placed beyond doubt by Potonié's description of such an accumulation on Heligoland, of which he gives a photograph. But such deposits are wholly local and possess no importance. Muck,[98] in the first edition of his work, referred to the occurrence, at several places along the North sea, of peat evidently marine in origin. Samples of the material were sent by him to Früh, who submitted them to microscopic analysis. One consisted almost wholly of decaying seaweed; when dried, it burned with small flame and foul odor, but it showed no characteristic of peat. Another, a brown substance washed up on the shore at Blankenberghe, contained no

[96] J. Macculloch, "A System of Geology," London, 1831, Vol. II., p. 339.

[97] Al. Brongniart, "Traité élémentaire de minéralogie," Paris, 1807, Vol. II., pp. 41, 46.

[98] F. Muck, "Die Chemie der Steinkohle," 2te Aufl., 1891, p. 164, footnote.

trace of algæ, but consisted wholly of fragments from land plants. The same is true of a specimen from the Dollart. After examining samples from all localities of alleged marine peat, Früh felt himself justified in the positive assertion that thus far no marine peat has been discovered.

The classification of peaty deposits has received much attention from many authors. The literature in America is somewhat limited, as, until very recent years, peat seemed likely to remain indefinitely without economic importance. Among the earliest attempts at classification is that by Shaler,[99] whose grouping was much in detail. He divided the forms into marine marshes and freshwater swamps; the former including grass marshes and mangrove marshes, growing above tide, as well as mud banks and eel-grass marshes, growing below mean tide; the latter including river, lake and upland swamps, each with two subdivisions. The grass marshes are along the coast where salt water bathes the roots of the plants, while freshwater swamps are above tide. Davis,[100] in discussing the freshwater deposits of Michigan, employed the terms bog, marsh and swamp; a bog is an area of wet, porous land, whose soil is mostly decayed or decaying vegetable matter, loosely consolidated and containing so much water as to tremble when one walks on it; the vegetation varies, but usually consists of mosses, sedges or grasses, or a combination of them along with shrubs and even small trees; a marsh does not shake readily when one walks over it, though it may be very soft and wet; the vegetation is mostly grass-like, though shrubs may be present in thickets; a swamp soil is firm, but wet, even to flooding at times, and bears trees and shrubby plants as the most important part of the vegetation. This grouping is not absolute, for the types may all be found in a single basin, the passage from one to the other being very gradual.

In Europe, where peat is of great economic importance, many students have expended great ingenuity in efforts to classify the

[99] N. S. Shaler, "General Account of Freshwater Morasses of the United States," Tenth Ann. Rep. U. S. Geol. Survey, 1890, pp. 261 et seq.

[100] C. A. Davis, "Peat," Ann. Rep. Geol. Survey of Mich., 1907, pp. 108, 109.

deposits, which are, practically all of them, freshwater, marine marshes being unimportant economically. Lesquereux, in 1845, recognized two general types of bogs, which he termed supraaquatic or emerged and infraaquatic or submerged, the former being above the waterline and the other at or below it. The prevailing classification in Germany recognizes the Hochmoor, equivalent to the Heathermoors of Scotland, and, in great part, to the supraaquatic of Lesquereux; the Wiesenmoor, Grünlandsmoor, Niedermoor, or Rasenmoor, equivalent to the bogmeadows of other lands; and the Waldmoor or forested bog. These are the Lyngmose, Svampmose, Hoermose; the Kjaermose, Engmose; and the Skovmose of the Danish authors. A similar division is that of Hochmoor, Flachmoor and Zwischenmoor, these being the terms employed by Potonié and some recent authors.

Potonié[101] has described a great moor in east Prussia on the delta of the Memel and Nemonien rivers, which shows the relations of the several types. Going eastward from the shore, one finds first the mud, which on the border is held by water lilies and other plants, referred to as "landmakers" because they are outposts. Higher plants, especially canes, occupy water areas, behind which there develops a meadow Flachmoor of sedges, where frequent floodings prevent growth of trees. Beyond that, foresting begins, and one reaches a moor of black alder, several kilometers broad. The surface is occupied by swamp plants, such as *Iris, Sium,* sedges, which endure well the periodical floodings of this zone. If the area were one of gradual subsidence, equal to the accumulation, the condition would continue for a long period. The surface rises gently and one comes to another flora, accustomed to somewhat drier soil, with alders, hops and nettles. Thus far, one has followed the Flachmoor or Niedermoor; but at a little distance beyond, swamp birches are seen among the alders. The latter soon disappear and the birch zone is reached, beyond which is a zone of forest with *Pinus sylvestris* and *Picea excelsa.* These form the Zwischenmoor or Waldmoor.

In this passage zone, the peat has risen so high that the surface is dry; the forest is here, but as one advances the trees become

[101] H. Potonié, "Die Entstehung," etc., pp. 35–40.

smaller because increasing accumulation of peat deprives them of their nutriment. Even exceptionally high floods cannot bring dissolved nutriment to them and they are dependent on rain, dew and dust. At length, the trees are displaced by *Sphagnum,* able to store away dew and rain, to remain moist on even a dry bed, to keep the area wet though it may be several meters above the water level. So one, in going eastward, is still on wet land. This is the Hochmoor, swelling as an hour glass—whence its name. But there is a still higher stage. On the Hochmoor, one's foot sinks deeply into the sphagnum-peat as he advances. At length a pond is reached; the rain collects in pools or small lakes, whence it flows to moisten the surrounding area. Plants thrive here because the changing water gives them nutriment. Reeds and sedges are seen and even *Pinus sylvestris* is present, though much smaller than on the borders of the Flachmoor. This great bog rests on a sandy deposit, with which are mingled the vegetable muds of the kurischen Haff.

As the problem of formation of coal beds is world-wide in scope, the essential features of those beds being practically the same in all lands, the study of peat accumulations must be as broad as possible, if the conclusions are to possess any worth for or against any theory. In the pages to follow, the results of studies by observers in many regions will be presented in detail. This may involve some repetition, but that will serve only to emphasize the importance of certain conditions, which have been overlooked or ignored in some contributions to the discussion.

Peat Deposits in the United States of America.—Marine marshes exist in extensive areas along the Atlantic coast from Maine to Florida, a region believed by nearly all observers to be subsiding. North from Florida, the tidal marshes are grass-meadows, ordinarily treeless. They are covered with grasses, reeds or coarse sedges and the upper surface is near the level of high water. Cook[102] has described those of New Jersey, which are typical of the whole coast from Georgia northward. Alongside of streams crossing the marshes there is a narrow ridge of dry land, but within a few yards one

[102] G. H. Cook, "Geology of New Jersey," 1868, pp. 24, 231, 233, 238, 300, 347–350, 361.

reaches the permanently wet area. Immediately below its sod, is mud or soft earth, which varies greatly in composition. Near the creeks, it is usually fine clayey mud with embedded roots, the whole evidently transported material; at a little distance, it is black earth or muck, formed in a swamp; while at a greater distance one finds only a mass of fibrous roots and vegetable matter with no admixture of earth or mud. The last two are of *in situ* origin. The "meadows" along the Passaic and Hackensack rivers, emptying into New York harbor, show an extreme thickness of 32 feet of "mud" resting on 8 feet of blue clay, while farther up the stream are great marshes resting on fine sandy material. One sees on the surface of these meadows great numbers of white cedar stumps and the mud is crowded with remains of cedar timber.

The condition is due to encroachment by the sea, whereby the treeless marshes advance inland and overrun the white cedar swamps along the streams; one finds at many places the old cedar forest buried in the tidal marsh, while the cedar swamp still exists at a little way beyond. The salt water kills the freshwater grasses and the trees on the border. In many places trees flourished 80 years ago, where one finds now only salt marsh muck. The white cedar is a very durable wood; trunks of trees killed by the salt water are still standing in localities where several feet of muck have accumulated around them.

Lyell[103] observed the effects of this encroachment in Georgia. In coming down to the coast, he found the trees becoming dwarfed and at length disappearing to be replaced by reeds; but in the marshes he saw the stumps and stools of cypress, still retaining the erect position in which they had grown. He quotes Bartram, who stated that when planters, along the coast of the Carolinas, Georgia and Florida, as well as westward to the Mississippi, bank in the grassy tidal marshes for cultivation, they "cannot sink their drains above three or four feet below the surface, before they come to strata of cypress stumps and other trees, as close together as they now grow in the swamps."

[103] C. Lyell, "Second Visit to the United States of North America," London, 1850, Vol. I., pp. 334–336.

When one reaches southern Florida, he finds a different type of tidal marsh. Northward, grasses and rushes are the plants which advance the land seaward, but at the south the mangrove is the agent. That plant abounds on coasts in tropical America and is found northward in Florida to lat. 30°, though it is not abundant above lat. 26°. The eccentric mode of growth exhibited by the special type under consideration, long ago attracted the attention of botanists. Bancroft[104] says that it rises from several strong woody roots which emerge from the ground for two or three yards before they unite at the trunk. Tough woody shoots, about three inches in circumference, descend from the trunk to take root and, as the tree increases in size, the shoots increase in number. These by their strength compensate for the looseness of the soil. The tree grows in a low, wet soil by the side of running water.

The Florida mangrove flourishes only in contact with salt water, being stunted by brackish water. Vaughan[105] describes it as attaining the height of 10 to 20 feet and as growing in water or so near it that the soil is saturated. The long seeds take root in water not more than one foot deep, leaves being put forth as soon as the surface is reached. Besides the tufty roots given off at the base, there are others originating at higher levels from the stem, which grow downwards and embed themselves in the soil. Shaler says that these can descend through 8 feet of water in order to take root. Each becomes a new tree to be multiplied in similar manner. Thus a tree may advance 20 or more feet in a century, the advance being checked only when the water is too deep or the waves prevent rooting. These growths, as described by Shaler and Vaughan, form dense thickets, a fringe, which is made denser by litter from the trees; so that débris from the land eventually fills up the space behind and the trees are killed. But, in the interval, a new fringe has been formed. In the moist area behind the growth, freshwater types displace the saltwater forms and a swamp results. Shaler

[104] E. Bancroft, "An Essay on the Natural History of Guiana in South America," London, 1770, pp. 76–79.

[105] T. W. Vaughan, "Geologic Work of Mangroves in Southern Florida," *Smithson. Misc. Coll. Quart. Issue,* Vol. V., 1910, pp. 461–464

conceives that the Everglades of southern Florida, with an area of about 7,000 square miles, owe their origin to outward advance of mangroves on shallows of the coast.

The freshwater swamps of the Atlantic and Gulf coasts are, for the most part, sharply distinct from the tidal marshes, even where the latter have encroached. Cook[106] has shown the relation in New Jersey by a section extending from Dennisville to Delaware bay, a distance of about one mile. The cedar[107] swamp begins at the edge of the low upland and gradually deepens to 15 feet. Like most of the cedar swamps in New Jersey, it has been cleared, but clusters of young trees up to 100 years old remain here and there on the surface, which is only a few feet above high tide. The cedar grows densely but slowly. Old stumps show more than 1,000 annual rings, but those near the bark are as thin as paper and the stumps rarely exceed 3 feet diameter, though some have been seen which were 7 feet. The swamp soil is black, peaty, 13 feet thick at Dennisville and, when dry, burns. It shows no admixture of foreign material and contains only 3.35 per cent. of ash, the water in the dried peat being from 12 to 16 per cent. It is very loose and porous, always full of water; the roots of the trees run through it in every direction near the surface, but do not penetrate to the solid ground. Where the peat cover is thin, the roots do pass through to the underlying soil, but, in that case, the wood is inferior and it cannot be utilized in manufactures.

Trunks of trees are buried at all depths and are so numerous that one has difficulty in thrusting a sounding rod to the bottom. Some had been blown over when rotten; others were merely uprooted. Some, blown down, lived for a considerable time afterward. The prostrated trunks lie in all directions and the conditions are precisely the same as those now seen on the surface of the swamp. Large stumps have been found, which grew over logs, now enveloped by

[106] G. H. Cook, *op. cit.*, pp. 301, 302, 355, 356, 360, 361, 484.

[107] The cypress or white cedar of New Jersey is *Chamæcyparis thyoides*, which is found in swamps from New Hampshire to Florida and westward to the Mississippi. The bald cypress is *Taxodium distichum*, a form surviving from the middle Tertiary, which extends from southern Delaware along the coast to Texas and up the Mississippi to southern Illinois.

their roots, and at the bottom are found worthless logs of cedar belonging to trees which were rooted in the solid ground below.

Shaler[108] has given a general description of the Dismal Swamp, an area of about 500 square miles, at only a few feet above tide level. It was much larger, but a great part has been reclaimed by draining. The peaty deposit rests on Pliocene sands, of which 10 to 14 feet are exposed on the border; but this is not wholly certain as the bottom has been reached at only one place within the swamp. C. A. Davis has stated recently that the peat is at least 15 feet thick and of good quality. On the western border is Drummond lake, 6 feet deep and somewhat more than 2 miles wide. Shaler says that, here and there within the swamp, one comes to drained areas of considerable size, one of which, embracing about 2 square miles, has long yielded fine crops of maize. He notes that *Sphagnum* has a very small place in this swamp and that it is an unimportant factor everywhere south from the Potomac and Ohio rivers, where the greater heat and decreased rainfall prevent its luxuriant growth. The most important peat-making plants in the region south from those rivers are canes, a grape, the bald cypress and the juniper with, in some localities, the dwarf palmetto—among these, he assigns the chief place to the common cane.

The greater part of the Dismal Swamp is under water during most of the time, but there are elevations rising not more than 3 feet above the general level; yet the drainage due to this slight elevation suffices for growth of pines belonging to the common southern species. In the main area, water-covered, one finds three trees, *Taxodium distichum,* the bald cypress; *Juniperus virginiana,* the juniper; and *Nyssa sylvatica,* the black gum. The juniper occupies spots usually somewhat desiccated during the dry season, but the others, being provided with special appliances, live where their roots are covered with water during even the growing season. The forest is very dense and passage through it is rendered difficult by projecting knees of cypress and the arched roots of Nyssa, while everywhere is a profusion of other plants. The surface is covered with a litter

[108] N. S. Shaler, Tenth Ann. Rep. U. S. Geol. Survey, pp. 293, 313, 321, Pl. 8, 9, 10, Fig. 29.

of fallen trunks, twigs and leaves. Shaler's plates from photographs taken in this forested swamp show the conditions thoroughly.

Shaler[109] has described the peculiar modification of structure characterizing the bald cypress. This is the greatest of the conifers east from the Rocky mountains and it is the most stately of all the trees on the eastern half of the continent. On dry ground or where there is no water during the summer half of the year, it shows no peculiarities; but where it lives in swamps, flooded during the growing season, the roots give off excrescences which project above the water, their height depending on the depth of water. These "knees" are subcylindrical and are crowned by a cabbage-shaped expansion of bark, rough without and often hollow within. Whenever these knees become permanently submerged during the growing season, the tree dies; as was proved in the New Madrid area, where, during the 1811 to 1813 earthquakes, the land sank permanently. In Reelfoot lake, within Kentucky and Tennessee, thousands of these long cypress boles still stand in the shallow waters, though 70 years have passed since the slight submergence of their knees. The effect of drowning is shown on a plate in the work previously cited. Many dead stems of cypress rise above the surface of Drummond lake, which is only a few feet deep. Lesquereux thought that these were once part of a floating forest.

Okefinokee swamp in southern Georgia is not wholly a forested swamp. It is larger than Dismal Swamp and more difficult to study. Harper[110] succeeded in penetrating it to a distance, all told of about 18 miles. Here and there are islands, raised a little above the swamp level, at times not more than 2 feet, often less. On those the slash pine and the black gum grow, while all around are sphagnous bogs in which are slash pine, as well as swamp cypress, with sedges, ferns, sundews, and pitcher plants. Pines are wanting where the muck is more than 4 feet deep, but the cypress grows densely until the depth exceeds 6 feet. Where that depth is exceeded, no trees are found

[109] N. S. Shaler, "The American Swamp Cypress," *Science*, O. S., Vol. II., 1883, pp. 38–40.

[110] R. M. Harper, "Okefinokee Swamp," *Pop. Sci. Monthly*, Vol. LXXIV., 1909, pp. 596–613.

and the surface is a "prairie." This type has an area of 100 square miles in the western part of the swamp, covered everywhere by water in wet weather, so that one may go in any direction in a canoe. Canes, pickerel weed and water lilies abound but *Sphagnum* is absent, as in this latitude it can grow only in shaded places. Stumps of cypress are abundant and the peat is about 10 feet thick. The Florida swamps, described by Harper and others in the official reports, show all types from the open marsh to the forested swamp. The cypress swamps of the Lake region have grass marshes near the water, which are separated from the dense cypress growth by a narrow belt of small willows. The peat in these deposits is worth little commercially, as it is crowded with logs and woody roots. The great Everglades area belongs to the stagnant water type.

The cypress swamps of the Gulf coast are like those of the Atlantic coast. Lyell[111] relates that, in excavating for the foundations of the New Orleans Gas Works, the contractor soon discovered that he had to deal not with soil but with buried timber; the diggers were replaced by expert axemen. The cypress and other trees were "superimposed one upon the other, in an upright position, with their roots as they grew." The State Surveyor reported that in digging the great canal from Lake Ponchartrain, a cypress swamp was cut, which had filled gradually, "for there were three tiers of stumps in the 9 feet, some of them very old, ranged one above the other; and some of the stumps must have rotted away to the level of the ground in the swamp before the upper ones grew over them."

Conditions in the cypress swamps are the same throughout, whether the prevailing tree be bald cypress or white cedar. The peat is formed by accumulation of litter in the dense forest and, for the most part, the swamps are due to impeded drainage on an almost level surface. The trees are rooted in the swamp material, which at times is of great thickness, more than 150 feet of muck, carrying cypress trees on its surface, being reported from Florida. Such trees find ample nutriment in peat containing less than 4 per cent. of mineral matter and they do not send their roots down to the solid ground. One sees growing amid such conditions not merely shrubs

[111] C. Lyell, "Second Visit," etc., Vol. II., pp. 136, 137.

but also majestic trees, such as cypress and gum, which, as well as the less imposing juniper, yield wood of great importance to the artificer.

The inland swamps of the northern states differ in many ways from the coastal swamps. They occur along river borders or in lakelet areas of the drift-covered region. In great part, the former are "wet woods" covered more or less deeply with water during several months of each year, but they show considerable stretches of true swamp. The swamps and marshes of the drift region are less extensive, but they afford better opportunity for studies bearing on the mode of accumulation. They have been investigated by C. A. Davis, H. Ries, N. S. Shaler and others, but the most comprehensive and most recent description is by Davis.

Davis[112] notes that very few highly organized plants can grow wholly submerged in water, and those are mostly endogens; 10 feet of depth seems to be the limit, although *Potamogeton* has been found rooted in 23 feet; other types, low forms such as *Chara* and the floating algæ are indifferent. Some plants, burweeds, arrowheads, reed grass, pickerel weed and water lilies can grow when partially submerged; while some land plants, shrubs and trees can endure long exposure to water about the roots. The surface growth on swamps is important. Elm and black ash swamps are of common occurrence and have, besides those plants, tamarack, spruce, willows, alders, with various heaths and mosses. They do not always show much peat, but what there is is well decomposed and is apt to contain much mineral matter. The greatest thickness of peat in these swamps is reported to be 10 feet. Tamarack (*Larix laricina*) and white cedar (*Chamæcyparis thyoides*) indicate the presence of peat, the latter growing densely on the surface of a deposit, 20 feet thick. Spruces (*Picea mariana* and *P. brevifolia*) also grow on thick peat; willows, poplar and alders grow on the thickest peat and in wet places; but the mosses, *Hypnum* and *Sphagnum*, grow only in advanced swamps.

[112] C. A. Davis, "Peat, Essays on its Origin, Uses and Distribution in Michigan," Rep. Mich. Geol. Survey for 1906, pp. 121–125, 128–134, 136–141, 153, 154, 157–159, 160–166, 203, 204, 208, 213, 269, 275, 279, 291.

Peat deposits fill depressions but, in some cases, are formed on almost level areas. Depressions more than 25 feet deep may be filled by algæ, by floating species of seed-bearing plants, by sedimentation, by plant growth from the sides or by a combination of these processes. A frequent succession is Chara-marl, on which rests a peaty soil in which plants take root; the land marsh moves out and tamarack advances on the deeper peat of the shore. As the water becomes shallower, each shore type moves out and is succeeded by the type behind—the water growing warmer and more aërated. Formation of peat on a flat space is much under the same conditions as those on the surface of a filled depression. When the drainage is poor, liverworts or some mosses take possession; if not too wet, rushes, sedges and grasses appear. Accumulation makes the place wetter and only the hardier plants remain. Sedges are the chief peat-producers under these conditions.

The process of filling a depression is often very complicated. In southern Michigan, the early stages are shown in many lakes, which are surrounded by zones of aquatic plants. More or less detritus, organic and inorganic, finds its way into the lake. Where the process is more advanced one can trace the whole succession.

The lowest deposit is formed of *Chara* and floating algæ. This is succeeded in the shallower water by the *Potamogeton* zone and that by the water lilies. Just beyond this one comes to the floating mat of sedges, extending on the water surface to a considerable distance from the shore and buoyant enough to support a considerable weight. The earlier stages may provide soil for rooting of the sedges at the shore line, but the mat itself is wholly unsupported for a considerable distance and is often 18 inches thick. Finely divided material from the undersurface of the mat increases toward the shore, where it becomes dense and the mat is no longer floating. Thus is built the solid peat, structureless, decomposed and nearly black. The surface rises gradually after grounding of the mat and, at each level, new plants appear. Shrubs and *Sphagnum* advance to be overcome in turn by tamarack and spruce, which in their turn are overcome by the marginal flora from behind. Tamarack accompanied by ferns grows far out on the bog.

The final stage is where the sedge mat closes over the surface and the underlying peat has become firm. Sedge is usually the chief factor in the later stages of lake destruction. At times, the mat is pressed down by the weight of trees growing on it. In one case it was found 6 feet thick, resting on semi-fluid peat. A section at one locality showed

		Feet.	Inches.
1.	Sphagnous peat	0	6
2.	Moss peat and shrubs	2	0
3.	Moss peat	0	3
4.	Coarse brown peat, stumps and roots	2	6
5.	Remains of shrubs	0	2
6.	Dark peat rich in sedge remains	2	0

It was impossible to determine the condition farther down as the peat was very wet, but sedges were recognized. Similar conditions were observed in other sections. These all show that the trees were rooted in the mat of pure vegetable material, even when it reposed on the water surface and that, while the trees were growing, the accumulation of peat was continuous.

After the mat has been grounded, *Hypnum* hastens outward from the shore, associated occasionally with some *Sphagnum*. When the surface rises 2 inches above the water level, ferns appear and they are followed by *Sphagnum*, which persists even when the surface is flooded. It is much hardier than *Hypnum* and, for that reason, it has been regarded as chief factor in the production of peat. But it is often absent, having been found in less than 30 per cent. of the localities examined by Davis. The first tree is the tamarack, which grows densely on the level of shrubs, but isolated trees are scattered over the open bog.

Chara-marl occurs frequently in southern Michigan but it was not seen anywhere in the northern portion of the state, where the general succession differs somewhat from that already given. The Chara-stage is wanting; pond weeds, pond lilies and rushes are of irregular occurrence and the sedge-zone is all important. Owing, probably, to absence of fragments belonging to the higher plants, the work of freshwater algæ is more apparent than in the southern peninsula. Algal lake, now covering only a few acres, is surrounded by a great wooded swamp, extending northeastward to a large lake and coming down almost to the water at the north end of Algal lake. The swamp loosestrife (*Decodon verticillatus*) forms the marginal zone. The bottom of the lake is covered with soft flocculent ooze, composed of unicellular algæ with diatoms as well as pollen from conifers. Davis conceived that peat of this type would be like cannel and he thinks that freshwater algæ may have been more abundant in Carboniferous times, when all types of plant life were lower than now. A similar material was found in a mature bog, where the section is

	Feet.
1. Coarse peat, with stumps, roots and fallen stems..............	5
2. Brown peat, good texture, quite plastic	5
3. Soft, light-colored peat, like that at Algal lake	4

These are the only localities in the United States whence this type of peat has been reported. Ehrenberg, Früh and Potonié have described the felt or Meteorpapier, as Ehrenberg termed it, which remains on swamps after floodwaters have been drained off. Potonié calls it Sapropel carpet, and he has given a photograph showing the material covering land plants of a swamp. But the phenomenon is of by no means rare occurrence in the eastern part of the United States. Davis has communicated by letter that he saw it in 1910 near St. Augustine in Florida, where the water of a swamp had been lowered; the felt was conspicuous on the tussocks, etc. In the Everglades of the same state, he found the felt about the grass and sedge stems in the level swamps. Here and there it contained a considerable quantity of calcareous matter, due perhaps to activities of Cyaphanaceæ present in the algal association. The same type of felt-like development is seen during springtime in marshes of the northern states, where the water drains off slowly. *Spirogyra* and other filamentous algæ sometimes cover the temporary ponds and are left as a felt-like cover when the water has been withdrawn. This felt breaks into small pieces as it dries and is added to the peat. The writer has observed it in very small patches on the New Jersey marshes; he has seen patches more than 10 feet square at many places in Rhode Island and Massachusetts. But in every case, the quantity is insignificant as compared with the mass of other vegetable material and this algal contribution must be wholly unimportant. At the same time, one can conceive of conditions which could render it important.

Shaler expressed the prevailing opinion when he asserted that the presence of moisture determines the distribution of plant life in swamp areas. Advance of swamp destroys the forest. He had seen many places on the coast of Maine as well as in northern Michigan and Wisconsin, where invasion by *Sphagnum* made the surface so wet that even the most water-loving trees of those regions could not maintain themselves. Davis, in his work on Michigan peats, has discussed the causes leading to the succession of vegetation in swampy areas. The shrubs growing at the water level are drought plants, though living where water is abundant; their leaves are linear or even scale-like; the cuticle is dense and the leaves are protected by a waxy or at times resinous coating—all contrived to prevent too rapid evaporation. The explanation of the condition is complex, but it depends mostly on the difficulty with which moisture can be extracted from peat. Once thoroughly air-dried, peat is almost impervious to water, so that plants growing on peat or a peaty soil suffer more from drought than those on other soils. Even when wet, it has little water for plants growing on it. A noteworthy fact in this connection is that some plants, growing near water level in southern Michigan, are found growing only on dry soils in northern Michigan. They find their drought-resisting ability equally essential in both regions. The distribution of these plants is explained by the fact that they have fleshy fruits, which birds eat during their southward migration and the seeds are scattered over moist areas. While the plants must be able to resist drought, they must be able to endure excess of moisture in some localities. Davis saw *Betula pumilla* and some willows living in places where their roots had been covered with one foot of water for several years.

The conditions of advance described by Davis are familiar in other states. They exist even on high swamp areas, as appears from Bradley's[112a] notes on the disappearance of meadows which were used as camping places in the Sierra Nevada. Fifteen years ago, these were open and covered with abundant grass. Originally, they were ponds or lakes which became filled with peat, on which grass thrived. As the material became less wet, tamarack seeds, blown in from the border, took root, but the young shoots were killed by the frequent fires. Since protection against fire has become complete throughout the region, the tamarack has advanced so as to occupy much of the surface, while pines are encroaching, which eventually will crowd out the tamarack and will occupy the whole area. The trees are rooted in the peat.

Bates[113] has shown that swamp conditions and luxuriant growth of trees are not incompatible. In describing the forests of Para, he says that one swampy area was covered with trees more than 100 feet high, all of second growth. In another swamp, the air was marked by a mouldy odor, the trees were lofty and the surface was carpeted with lycopodiums. Farther down in this area, where the ground was more swampy, wild bananas, great palms and exogens grew luxuriantly and were covered with creepers and parasites; while the surface was encumbered with rotting trunks, branches, leaves, and the whole was reeking with moisture. Kuntze, already cited, states that the tropical swamps are densely wooded. Observations by other authors will be referred to in another connection.

Peat Deposits in Europe.—The importance of peat as fuel in Europe has led to thorough investigation of that material from every conceivable standpoint. The literature is so extensive and, in great part, so excellent that one, compelled by limits of space, finds himself embarrassed in selection of authors as well as of matter.

Lesquereux[114] long ago proved that *Sphagnum* is not the important factor in peat-making; he recalled attention to Ad. Brongniart's

[112a] H. C. Bradley, "The Passing of Our Mountain Meadows," *Sierra Club Bull.*, Vol. VIII., 1911, pp. 39–42.

[113] H. W. Bates, "The Naturalist on the River Amazons," London, 1863, Vol. I., pp. 44, 47, 50, 51.

[114] L. Lesquereux, "Quelques recherches sur les marais tourbeux," pp. 32, 111, 121, 137; 2d Geol. Surv. Penn., Rep. for 1885, pp. 107–121.

observation that evaporation from that moss is proportionately less than from other plants; and he showed that growth of the moss is checked by freezing and that the plant cannot live in deep shade or under forest trees such as oaks, pines or beeches. He seems to be the first to note that marls covering peat bogs contain impressions of plants.

Lesquereux's conception of the mode of filling depressions from the sides differs somewhat in detail from that given for the United States. Shallow ponds are invaded by vegetation, which forms a mould in which water plants take root. The basin is filled by their decay, the surface becomes humus in which plants of other types grow, giving meadows or forests. The filling is rapid in the early stages. Pools of quiet water are invaded by confervæ, mingled with infusoria, microscopic plants and small shells, which by decay cover the bottom. At times, 6 to 10 inches of this deposit may accumulate in a year. When the water is deep, the same result is reached by another process—the prolonged growth of certain floating mosses, especially of some species of *Sphagnum*. Those, pushing out from the sides, form a thin cover, in which grasses, sedges and other water-loving plants grow. Eventually, this becomes compact enough to bear the weight of trees, even of dense forest; until, becoming too heavy, it either breaks or is pressed slowly to the bottom and covered with water. This, he asserts, is no hypothesis but the statement of actual fact.

The lac d'Etaillères, near Fleurir in Switzerland, is open water in an extensive series of peat bogs. Prior to the year 1500, it was the site of a forest; but in that year, according to legend, the forest disappeared and it was replaced by two lakes. The lakes still exist and in quiet water one can see the prostrate trees on the bottom. But a new carpet has already spread over much of the surface, which in turn will become forested and will sink. Thus one may find superimposed beds of decomposing vegetable matter, each consisting of remains of small plants below but of forest remains above. An analogous condition exists in Lake Drummond of the Dismal Swamp, where the bottom consists of a forest cover, once at the top but now under water, while vegetation is encroaching from the sides. It is quite possible that this explanation of the Lake Drummond condition is correct, but that lake is shallow, only 6 feet, and the trees are erect; in the deeper lac d'Etaillères, the trees were prostrated by breaking of the mat. To illustrate the succession in such a case, he gives the section of a bog in Denmark:

	Feet.	Inches.
1. Fibrous yellow peat with undecomposed mosses........	3	8
2. Oak layer, wood still sound, trunks 2 to 3 ft. diameter.		
3. Peat, yellowish	6	
4. Birches, prostrate, *Betula alba*	3	0
5. Black peat	4	0
6. Pines, 6 to 10 inches diameter, most of them pointing toward center of the basin, retaining their branches, embedded in a mass of leaves, cones, etc.	8	0
7. Black compact peat	4	0

and the bottom not reached. This peat was mined for fuel, the works being extensive. The general description by Lesquereux shows that the conditions are not wholly the same in his localities as in many areas within the United States. They suffice to show that *Sphagnum* is a late arrival, though in Switzerland, as in some other portions of Europe it is more important than in this country, where sphagnum-peat rarely exceeds 3 feet.

As illustrating this, one may cite Vogt's[115] description of a Hochmoor at the Ponts of the Canton Neuenburg. This lies between two villages built on limestone benches on opposite sides of a valley. In the middle ages, each village was visible from the other, but that is no longer the case. The bog has raised itself, hill-like, growing most rapidly along the middle line. This mass is *Sphagnum* and its mode of growth shows well the ability of that moss to retain water, so as to thrive at considerably above the water level.

Heer[116] says that life on land began with minute forms and few types. So, in the water, algæ begin the work. Even pure fresh-

[115] C. Vogt, "Lehrbuch der Geologie," 2te Aufl., Braunschweig, 1854, Vol. II., p. 110.

[116] O. Heer, "Die Schieferkohlen von Utznach und Dürnten," Zurich, 1858, pp. 1–4.

water, exposed to air and light, is full of minute plants, with boundless capacity for multiplication, forming in vast legions, which sink and form a layer of organic material, the basis of formations composed of higher organisms. These are followed by floating mosses, which, in spite of their small size, soon produce a great mass of organic material. The bladderworts, water milfoils follow and the water lilies spread their leaves over the surface; reeds press out from the shore and sedges of various kinds form a wickerwork of roots, which gradually spread over the whole depression and water is no longer visible. Meanwhile the peat has been growing denser, drawing water from below and keeping the bed moist. In it nestle the milfoils and heaths. The lake closed, woody plants encroach, *Betula* and then *Pinus sylvestris*. But the latter does not grow high, breaking off after attaining a certain height and weight, sinking into the underlying soft material, there to be destroyed and converted into peat as are the shrubby plants. These trees are readily overthrown by the wind and the peat is crowded with the overturned trunks of birch and fir. The harder parts offer prolonged resistance to chemical change and are embedded in a pulp-like mass derived from the softer parts. The conditions in all stages are recognizable in Swiss deposits. The succession may be varied by climatic changes, whereby a Waldmoor may be converted into a Torfmoor and that in turn into a Waldmoor again.

Früh's[117] descriptions of conditions in Switzerland and Germany are much like those given in later years for localities in the United States, though the succession of events may differ somewhat in detail. At the same time, the Hochmoor or *Sphagnum* deposit seems to be built up on the Rasenmoor, composed of *Cyperaceæ, Phragmites* and *Hypnum;* islands of Hochmoor were seen occasionally in a Rasenmoor. Lorentz is cited as having examined 57 moors, of which 31 were Hochmoors developed on Rasenmoors. Früh investigated Hochmoors in Steiermark, the Bavarian highlands and in Switzerland, all of which showed that *Sphagnum* is a late arrival in

[117] J. J. Früh, "Ueber Torf und Dopplerit," pp. 5, 7–9, 15, 18, 20.

the peat. In the great Digenmoors of the Bavarian highlands he found

		Meters.
1.	Black peat, with *Sphagnum*	1 to 1.2
2.	Homogeneous black-brown, compact, plastic peat, with layers of crushed birch stems; a few specimens of *Sphagnum,* but 90 per cent. of the mass consisting of roots of *Cyperaceae*	1 to 1.5
3.	Wood layer of conifers	0.4 to 0.6
4	Glacial drift.	

He gives measurements from fourteen localities in Switzerland, only one of which failed to show the succession observed in the section. The exception is a Hochmoor without Rasenmoor foundation and resting directly on a layer of wood remains. One group seems to contradict Sendtner's generalization that Hochmoor accumulates only in localities where the water is not calcareous. This, the "Todte Meer," is a typical living Hochmoor, near Willerszell, bearing on its surface many hummocks nearly equal in height and basal diameter, and bordered by a mountain stream, whose drainage area is in a limestone region. It shows

		Meters.
1.	Hochmoor, *Sphagnum*	0.2 to 0.3
2.	Felted Rasenmoor, upper part consisting of *Carex* and *Arundo,* with scattered algæ; lower part with *Hypnum*	3
3.	Almost pure well-preserved *Hypnum.*	
4.	Clay and gravel.	

He finds a simple explanation in the fact that the stream, at high water, does not wet the *Sphagnum.* It may be well to note here that in Michigan, according to Davis, *Sphagnum* is indifferent to the character of the water, the presence of calcium carbonate in no wise affecting its growth.

Früh reports 48 Hochmoors in the Alpine region as originating on Rasenmoors. V. Bemmelen and Staring are cited as having proved the same relations for the provinces of Orenthe, Friesland and Gottingue in Holland. The Rasenmoor does not require hard water, for the vast moors of the Rhine and Maas area are watered by those streams, which contain only 65 and 41 millionths of calcium and magnesium compounds. The relation between Hochmoor and

Rasenmoor is not always apparent as either one may be very thin and the other very thick. In his later, great work on the Swiss moors, Früh has described with much detail all the Swiss deposits and he has offered generalizations which will be considered in another connection.

It had been suggested by some observers that the tree trunks found in the bogs had been drifted into the depressions, but Früh asserts without qualification that they are in place. The condition is wholly normal. A. Geikie,[118] after noting the differences in physical structure as well as in vegetation shown by successive portions of a bog, says that remains of trees are common. Some are embedded in soil underneath the bog; others are in the heart of the peat, proving that the trees lived on the mossy surface and finally were enclosed in the growing peat. This is illustrated by a sketch of a peat-moss in Sutherland. J. Geikie[119] has given much information respecting the Scottish bogs but it will suffice to cite only his later work. The bogs have yielded many species of trees, all of them indigenous. The trees are *in situ,* each rooted in the kind of soil preferred by living examples. There are few acres of lowland bog in which trees have not been found. They occur even in the Hebrides, where trees now are practically unknown. Occasionally, more than one forest bed is present. At Strathcluony, three tiers of Scotch fir were seen, separated by layers of peat. Several tiers were exposed in a railway cutting across the Big Moss; one of standing fir trees with branching roots at 6 feet below the surface, a second at 12 feet and a third at 4 feet lower; so that, counting the surface growth, four different forests have existed there since the bog began.

Aher,[120] in the Bog reports, says that trees in the Irish bogs "have generally 6 or 7 feet of compact peat under their roots, which are found standing as they grew, evidently proving the formation of the peat to have been previous to the growth of the trees." On

[118] A. Geikie, "Text-book of Geology," 3d Ed., London, 1893, pp. 478–480.

[119] J. Geikie, "The Great Ice Age," 3d Ed., London, 1895, pp. 286–293, 303.

[120] Cited by S. S. Haldeman, in 2d Ed. of R. C. Taylor's "Statistics of Coal," Philadelphia, 1855, p. 169.

the same page Haldeman notes that it is a remarkable fact, although very common, that successive layers of trees or stumps, in erect position and furnished with their roots, are found at distinctly different levels, at small vertical distance from each other.

Grand' Eury,[121] noting that the plants, active in peat-making, are not the same in all cases, maintains that a distinction must be made between peat, properly so-called, and peat of the *marais.* The former is supraaquatic, covers high plateaus and is formed chiefly by *Sphagnum,* with some other water-loving mosses. Unaccompanied by these, other plants in similar conditions give only soil. Such peat is rarely transformed into a compact *charbon* and it is obscurely stratified. The peat of *marais* is formed on low grounds, along the borders of rivers, lakes or the sea, often in extensive areas. In such places, *Arundo* grows rapidly along with *Scirpus palustris* and reeds as well as with *Hypnum, Nymphœa* and other semi-aquatic plants. This peat may be divided by sandy deposits and at the bottom one finds a muddy peat, almost without structure. It occurs in Holland and on the shores of the Baltic, the marshes being of great extent in both regions. Fossil peat occurs at Utznach in Switzerland.

Still different are the peats of wooded swamps and swampy forests. In depressed areas, where the forests have been killed by swamp plants, the peat, formed of herbaceous plants and prostrate stems, accumulates rapidly. He refers to the wood at Kiögge near Copenhagen, which the Danish naturalists had regarded as due to transport; but Lesquereux had shown that it is in place, the trees having been overturned by the wind—a condition observed in the present forests near by. The mass is composed almost wholly of birch and the upper part consists of empty barks entangled in a mud or half liquid paste, coming from decomposition of the wood.

Grand' Eury examined in the Ural a peat of swamp-forest origin, a mass of herbaceous plants and débris of trees. Stumps rooted in the mass were seen at two horizons in the upper part and others were scattered below. Many stems and branches lie prostrate and,

[121] C. Grand' Eury, "Memoire sur la formation de la houille," *Ann. des Mines,* 8me Ser., Tome I., 1882, pp. 197–202.

at the bottom, a considerable portion is formed of barks, wood, leaves and other débris, transported and deposited in the water. Roots can be seen penetrating the gray clay on which the deposit rests. On the borders, the peat has not been changed in position and it is felted and herbaceous. In one part it seems to be composed exclusively of transported plants, there being barks of flattened birches; some laminated portions are formed of humefied epidermis material.

No reasons are given for assigning a great portion of the mass to transported material, the matter being taken apparently as beyond dispute; but one may surmise that the presence of stumps rooted in the peat, the prostrate trunks and the fragmentary condition of the enclosing material may have been for him convincing. Grand' Eury did not believe that trees would grow in peat and the fragmentary condition of plant remains was proof that they had been washed in. The conditions, described by him, are precisely those which are familiar in bogs, for which no conception of transport is admissible.

The Danish swamps were studied by Steenstrup[122] long ago; his grouping resembles that employed by the German students. The most important is the Waldmoor or Skovmose type occupying depressions in Quaternary deposits, often more than 30 feet deep. Where the area was small, the sides were abrupt and the trees growing on them eventually fell into the bog, where they have been preserved. In depressions of great extent, one finds an exterior wooded zone surrounding an interior or central bog zone. The latter resembles the Lyngmose, the heather or Hochmoor stage.

The central area of the Skovmose is very regular. It rests on clay derived from the borders; above which one finds ordinarily one and a half to even four feet of amorphous peat, becoming pulpy in water and containing indeterminable plant remains. The peat is very pure in normal bogs, but layers of calcareous or silicious matter are not unknown. A layer of hypnum-peat rests on the amorphous deposit, 3 to 4 feet thick, containing *Pinus sylvestris*, which grew on the spot, at times forming a forest on the swamp. The trees were

[122] Steenstrup, as summarized by Morlot, Trans. in *Ann. Rep. Smithsonian Inst.*, Washington, 1861, pp. 304 et seq.

stunted and grew slowly amid unfavorable conditions, there being 70 annual rings to the inch; yet the trees lived for several centuries. In the larger swamps, two or even three layers of pine stumps are found, *in situ*, with their bases and roots well-preserved. As the surface became higher, and drier, the earlier mosses gave place to others; *Sphagnum* appeared and, at length, heathers. The pines yielded to the birches and those to alders, hazel bushes and *Corylus*. This succession is found only in the central zone; the deposit is too thin on the border.

Weber[123] after prolonged study of peat areas in northern Germany, grouped the peat producing plants into (1) those which form the moor; (2) those which grow on the peat; (3) those which love peat or are bound to it. The best illustrations of the relations of these groups are in moors which began in post-glacial time and have continued until now. As the result of his examination, Weber succeeded in determining the stages in development of the bog and in determining the part played by the several groups of plants. He presented a classification which has been accepted by many of the later students. This will be given in detail as applied to the Scandinavian deposits.

Somewhat earlier, Blytt[124] had discovered that in western Norway the typical succession is

		Feet.
1.	Sphagnous peat, about	5
2.	Forest bed, chiefly of Scotch fir.	
3.	Peat more compressed than that of No. 1, about	5
4.	Forest bed with oak stumps and myriads of hazel nuts.	
5.	Glacial deposits.	

But in eastern Norway, there are four peat layers alternating with three forest beds. In Denmark he finds equally distinct evidence for successive wet and dry periods. In summing up the conditions observed in Norway, Sweden and Denmark, he finds record of the following climatic changes:

[123] C. A. Weber, "Aufbau und Vegetation der Moore Norddeutschlands," *Engler. Bot. Jahrb.*, Vol. 40, 1908, *Beiblät.*, No. 90, pp. 19–34.

[124] Blytt, cited by J. Geikie, "Great Ice Age," p. 495.

1. Arctic freshwater beds, containing *Salix polaris, S. reticulata, Betula nana,* etc. A semi-continental climate.

2. Sub-glacial stage, with *Betula odorata, Populus tremula, Salix,* etc. The moors were wet, the climate humid; equivalent to the Danish "birch or aspen period."

3. Sub-Arctic stage, drier, many bogs became dry and were overspread by forest growth; Scotch fir (*Pinus sylvestris*) makes its first appearance.

4. Infra-boreal stage, climate again humid; the flora of Denmark is still of true northern type; *Pinus sylvestris* the common tree.

5. Boreal stage, climate drier and forests overspread the bogs, forming a root bed; *Corylus* and oak abundant.

6. Atlantic stage, climate mild and humid; *Quercus sessiflora* abundant in Denmark and southern Sweden; this is the Danish "oak period."

7. Sub-boreal stage, drier than the last; many peat bogs dried up and became forested.

8. Sub-Atlantic stage, bogs again wet and the youngest peat layer was formed; this is the Danish "beech or alder period."

9. Present stage, the bogs are drying and are becoming forested.

Stages 1 to 4 are wanting in the low level bogs of the Scandinavian coast as that region was still submerged.

The peat deposits of Sweden have been studied by H. and L. von Post, Andersson, Sernander and others, and those of Finland by Andersson. It suffices for the present to present only the salient facts as recorded by L. von Post,[125] reference to the work of some others being deferred to a later portion of this work. Von Post's studies were made in the province of Narke, southern Sweden. His grouping is essentially the same as that offered by Weber but he gives details, necessary to the present discussion, not noted by other students. He finds the following types of deposits:

Limnische. I. 1. Allochthonous mineral deposits made in open water; here are clay, with diatoms, poor in plankton, and clay-gyttja, which is clay with much plankton and diatoms. 2. Allochthonous organic sediments, including (*a*) plankton-gyttja, in open, comparatively deep water, gray to green, more or less elastic, composed of plankton, algae abounding; (*b*) detritus-gyttja, in comparatively shallow water, from *Potamogeton* and *Nymphæa*, red-brown to yellow-black, granular, mostly plant débris with some plankton; (*c*) Schwemmtorf, composed of plant detritus; (*d*) Ufertorf, like the last and formed very near the line of low water. It contains lenses of Lake and of Swamp peat.

[125] L. von Post, "Stratigraphische Studien über einige Torfmoore in Narke," *Geol. Foren. Forhandl.*, Bd. 31, 1909, pp. 633–640, 644, 647.

II. Autochthonous organic deposits. The Lake peat including (*a*) *Phragmites* peat, clear yellow, composed of fibrous roots with reeds and some gyttja; (*b*) *Equisetum* peat, like the last in structure, but the color is coal black.

Telmatische. I. Swamp or Niedermoor peats, including (*a*) Magnocaricetum peat, consisting of sedges with *Amblystegium* as accessory, yellow to yellow-brown; (*b*) *Amblystegium* peat, consisting of stems and leaves of that plant with some sedge constituents; (*c*) Bruchpeat, red to black, amorphous humefied peat detritus, *in situ*, with identifiable roots of sedges.

II. Hochmoor peats, (*a*) Cuspidatum peat, bright colored *Sphagnum cuspidatum* and other water-loving mosses, with remains of *Scheuchzeria, Carex* and *Eriophorum*.

Semi-Terrestrische. I. (*b*) Vaginatum peat, *Sphagnum* with *Eriophorum vaginatum* roots and stalks, these often making up one half of the mass, humefied and dark colored; (*c*) *Sphagnum* peat in lenses with *Cladina* remains between clear brown layers of *Sphagnum* with *Eriophorum*.

II. Forest peat, (*a*) Alder forest peat, red-black, amorphous, consists of *in situ* deposited detritus of an alder swamp forest. Remains of alder are recognizable; *Cenococcum geophilum* abundant.

Terrestrische. (*b*) Birch forest peat, like the last, but commonly dark colored, deposited in a birch swamp forest; (*c*) Forest peat, rich in *Eriophorum* and *Sphagnum*, as a rule, dark colored, almost always with stumps and other remains of Scotch fir; (*d*) Forest mould, dark, composed of wood detritus and grains of humus, with stumps.

All of these types from Lake peat down are autochthonous. The upper limit of the basin or limnic deposits is at the normal line of low water; the shore or telmatic deposits are in the space covered at high water, while the terrestrial are on forested areas, rarely covered with water. The alder swamp is the passage zone to the terrestrial. Von Post confirms Blytt's conclusions respecting the alternation of dry and humid periods, and shows how, during the less humid times, forests invaded the peat deposits and in some cases covered the surface of pure peat with a dense growth. He presents sections from a number of localities. One from the Åsta moor shows

A. *Sphagnum* peat, 85 centimeters, with, at 80 centimeters, a mass of fir stumps rooted in the peat and with coaly matter between the stumps.

B. Strongly humefied cuspidatum peat, 10 centimeters.

C. Sedge peat, 30 centimeters, has much *Sphagnum* above.

D. Alder and birch swamp forest peat, with small stumps of alder, birch willow and a great quantity of *Cenococcum geophilum*, 15 centimeters.

E. Shore peat, like transported peat, 25 centimeters, roots of *Carex, Equisetum* and *Phragmites.*

F. Plankton-gyttja, 40 cm. with remains of infloated *Phragmites, Equisetum*, etc., some pollen of *Picea* in upper portion.

G. Clay, 50 cm. rich in saltwater diatoms.

As interpreted by Von Post, one has here at the bottom, a deposit of plankton material or Sapropel. It was invaded by the shore peat, on which a forest of birch and alder grew for a short time amid unfavorable conditions, as the swamp was overflowed at times; this condition became more marked and a sedge swamp followed, in which *Sphagnum* gradually gained control. Still later, for a short period, during which accumulation of peat continued unchecked, the moor was covered with a dense growth of firs; but as the moisture increased, the non-water-loving elements disappeared and a *Calluna-Eriophorum* moor occupied the area. Sections in Skarby lake complex show the same general features as those observed elsewhere in this region. Though there are differences in detail, the story is practically the same throughout. The open water deposits, gyttjas rich in plankton material, form the lowest stratum resting on clay or sand; on this is the shore peat, which gradually passed across the basin. Then came the time of decreasing moisture; alders advanced on the peat surface, now subject to only occasional overflows; they were succeeded by birches, which were rooted in the alder peat; and finally came the great forests of Scotch fir growing in the birch and alder peat, to be succeeded by *Sphagnum*-Hochmoor peat in the moist Sub-Atlantic stage. Peat-making was continuous in the forests and each type of forest peat has its own group of minor plants.

Buried Peat Deposits.—Some authors have contended that peat deposits on the land are not likely to be preserved because, exposed to air, they must be affected by atmospheric conditions and eventually must waste away. Under such conditions, it is certain that only such accumulations of vegetable material as are deposited in water-filled basins would be preserved. But the supposed conditions are purely hypothetical and are not in accord with those existing in nature. Indeed, one looking at a peat deposit, many feet thick, would have difficulty in conceiving how there could be uniformity of conditions for a period long enough to permit wastage of so great a mass, almost impermeable to water after having become thoroughly air-dried. But *a priori* reasoning is unnecessary; for, as Lesquereux recognized long ago, burial of peat bogs is part of the normal sequence of events.

Dawson[126] has described an early Quaternary bog which he saw in Nova Scotia. It underlies 20 feet of bowlder clay and pressure has made the peat almost as hard as coal, though it is tougher and more earthy than good coal. When rubbed or scratched with a knife, it becomes glossy; it burns with considerable flame and approaches the brown coals or poorer varieties of bituminous coal. It contains many roots and branches of trees apparently related to spruce.

Areas of peat buried under glacial drift are numerous in the New England states as well as in New Jersey and some of them will be mentioned in a succeeding section. Newberry,[127] many years ago, collected all the observations then available for states west from the Alleghany mountains. In Montgomery county of Ohio, E. Orton found a bed of peat, 15 to 20 feet thick, the surface covered with *Sphagnum*, grasses and sedges. It contains coniferous wood with bones of elephant, mastodon and teeth of giant beaver; and it underlies 90 feet of gravel and sand. At many places in Highland county of the same state, wells have reached a stratum of vegetable matter and, at Cleveland, a "carbonaceous stratum" has been found at 20 feet below the surface. A similar condition exists at Lawrenceburg, Indiana, as well as at many places along the Ohio; and J. Collett reported that, throughout southwestern Indiana, there is an ancient soil, 2 to 20 feet thick, with peat, muck, rooted stumps, branches and leaves, at 60 to 120 feet below the surface. This deposit is known locally as "Noah's cattle yards." The same condition is reported from a portion of Illinois. The great forest bed of Iowa, discovered by McGee at a later time, is in part a buried bog. Leverett, Taylor, and Goldthwait have described autochthonous peat bogs buried under glacial drift at many localities within the Mississippi area.

[126] J. W. Dawson, "Acadian Geology," 2d Ed., London, 1868, p. 63.

[127] J. S. Newberry, "Surface Geology of Ohio," Geol. Survey of Ohio, 1874, Vol. II., pp. 30-32.

In America, observations as recorded are very few and, for the most part, they are merely incidental, as until very recently the geological importance of peat was not recognized; but in Europe the case is very different; one finds there such a wealth of illustration as to cause surprise that any student should entertain doubts respecting preservation of peat deposits by burial under sediments. A few citations must suffice.

J. Geikie[128] says that peat bogs often pass below the sea. In the harbor of Aberdeen, trunks of oak are brought up and at a little distance away, peat was seen below the sea level covered with 10 to 12 feet of sand. This bed, enclosing trees, is known to extend for some distance into the bay. In the Carse lands, the river Tay has cut down to a peat bog, now forming the river bed and underlying about 17 feet of alluvial material, which near the top contains cockles, mussels and other marine forms. This extensive peat deposit of the wide Carse area rests in part on alluvial sands and in part on marine clays. The peat is highly compressed and splits readily into laminæ, on whose surfaces are small seeds and wing cases of insects. As a rule, but not always, it is marked off sharply from the overlying clay and silt. That it represents an old land surface is certain but it is equally clear that, in great part, the vegetable débris on top was drifted in from localities higher up in the valley, for the upper part of the peat contains, at times, layers of silt and twigs, while branches as well as trunks are scattered through the lower 3 or 4 feet of the overlying silt. The conditions are the same in Carse lands on both sides of Scotland and they exist in the Hebrides.

Prevost and Reade[129] have described a peat bed covered by a thick deposit of sediments. The exposed portion is a dark-brown peaty mass, containing large and small branches, roots and rootlets, the latter passing into the underclay. Some large boles and an occasional stump were seen on the upper surface. The authors note as a remarkable fact, that this bed resists erosive action by the river

[128] J. Geikie, "The Great Ice Age," 1895, pp. 290–293.

[129] E. W. Prevost and T. M. Reade, "The Peat and Forest Bed at Westbury-on-Severn," *Proc. Cotteswold Nat. Club,* Vol. XIV., 1901.

as well as by the more energetic bore, so that it projects as a promontory. Strahan[130] measured the section exposed during excavations for docks on Barry island. The succession is

1. Blown sand, *Scrobicularia* clay, sand, shingle, with strong line of erosion below. 2. Blue silt with many sedges. 3. Upper peat bed, 1 to 2 feet thick. 4. Blue silty clay with many sedges. 5. Second peat bed, thin. 6. Blue silty clay with sedges. 7. Third peat bed, with many logs and stools, roots in place underneath. 8. Blue silty clays with reeds, willow leaves and freshwater shells. 9. Fourth peat bed with large trees and roots in place and numerous land shells. 10. An old soil with roots and land shells. 11. Rock in place, at 35 feet below the Ordnance datum.

Here as in the Carse area of Scotland, the peat underlies a deposit containing marine shells.

Lesquereux[131] cites a French author, who found at many places in the Department of Nord alternations of peat and sand, the latter containing marine shells. He notes that when the growth of peat is checked by dryness, a crust forms, which is a parting between the old and the new peat. In the valley of the Somme, he found, underlying 8 feet of clay and concretionary limestone, 23 feet, 4 inches of peat in 15 layers, with the partings distinct and the layers differing in character. Alternations of clay, peat and calcareous concretions are not rare.

Geinitz,[132] more than twenty-five years ago, studied the dune-covered bogs near Rostock. At a later period he had opportunity for more detailed examination and his observations are important from several points of view. At the bathing station near Graal, the section shows at the bottom, sand of the Rostock plain, on which rests a one-foot layer of peat, containing stumps of trees which grew on it. The dune formerly covering this deposit has been removed for some distance, exposing the peat, but it still remains at a little way landward. Beyond the dune, one finds a forest of great beeches and oaks, with the peat bed covering the surface between them.

[130] A. Strahan, Mem. Geol. Survey, "Geology of the South Wales Coal Field," Part III., 1902, pp. 87–93.

[131] L. Lesquereux, Ann. Rep. 2d Geol. Survey of Penn. for 1885, pp. 116–118.

[132] E. Geinitz, "Nach der Sturmflut," *Aus der Natur,* Vol. IX., 1908, pp. 76–83.

When he looks at the dune surface, he sees, as it were, shrubs rising out of the sand, some short thick stems of beech and oak; but they are not shrubs, they are the still living parts of trees, the same in age and growth as those standing in the open forest. They have been buried by the advancing dune. A mighty storm flood, tearing away the sea wall and removing part of the dune, will expose vertical trees standing in the sands as in the Coal Measures sandstones. At present, one sees advancing masses of sand burying the trees, which grow on low-lying moors. At another locality, storms, during recent years, have exposed an older peat deposit, underlying the sands of the Rostock plain. The outcrop extends hundreds of meters along the shore and shows that the peat is a moss peat, which bore a forest of Scotch fir. There, as also near Graal, the waves have torn off fragments of the peat and have worn them down into elliptical form similar to that of the beach pebbles. Barrois[133] has referred to similar origin of peat pebbles on the shore of the British channel, where some neolithic deposits of peat are exposed to the waves. The fragments of peat are rolled, rounded and eventually transformed into true ellipsoidal pebbles.

Lorie,[134] in his fifth contribution to the surface geology of Holland has gathered together all the available information respecting the buried recent peat deposits of that region.

In all probability the Zuyder Zee was filled with peat prior to the catastrophe of the middle ages, but the only vestige is on the island of Schalkland, where one finds 5 to 7 meters of peat covered with a meter or more of marine clay. The same condition exists on the river Y near Amsterdam and in the province of Zeeland as well as in the west part of North Brabant in Belgium. The peat bed near Oudenbosch, in the latter province, is 0.75 meter thick and underlies 0.65 meter of sediment. It is readily traceable from that village across Zeeland into western Flanders of Belgium, and thence to the coast at Ostend in Belgium and Dunkerque in France, a dis-

[133] C. Barrois, "Observations sur les galets de cannel-coal du terrain houiller de Bruay." *Ann. Soc. Geol. du Nord.*, Vol. XXXVII., 1908, p. 7.

[134] J. Lorie. "Les dunes intérieures, les tourbières basses et les oscillations du sol." *Archives Mus. Teyler*, 2me Ser., Vol. III., 1890, pp. 424–427, 444, Pl. 2.

tance of more than 60 miles. Lorie cites Belpaire père, who says that it is one to 3 or even 4.5 meters thick and that it rests mostly on blue clay, though in some localities on fine sand. It is double near Ostend, where the lower bed is black, compact, with roots of reeds, while the upper bed contains no reeds but has woody fibers, apparently roots of heath plants. The peat and its overlying clay are sometimes continuous under the dunes and shore, as is also the case on the island of Walcheren in Zeeland. Trees, rooted in the subsoil, occur frequently in the peat. Belpaire fils says that the thickness of the peat and that of the overlying clay vary from 1 to 3 meters and that the clay level is never above high tide. On the left bank of the Escaut (Scheldt) as it flows from France across Belgium the peat is almost a meter and a half thick, but the clay, 2 to 3 meters, decreases as it recedes from the river. Lorie says that Rutot found a divided peat near Blankenberghe in Belgium. Reference to Rutot's[135] publication shows that the section is

		Meters.
1.	Shore sand	2.30
2.	Gray sandy clay	0.60
3.	Gray sand, with bed of *Cardium* midway	1.10
4.	Pure peat	2.00
5.	Gray sand, slightly argillaceous	0.40
6.	Sandy clay	0.50
7.	Gray, argillaceous sand	2.50

The peat underlies a marine sand and overlies a sand which is but slightly argillaceous.

In 1852, Harting, as cited by Lorie, discovered hard dry peat at 10 to 12 meters below the surface in Amsterdam. Ghyben followed this eastward toward the Wecht river. For much of the distance, it is covered with marine sand, but at that river it is covered with the main mass of peat, constituting the boundary between the sandy diluvium and the alluvial deposits. In later years it became possible to confirm and to extend the early observations, for many borings have been made along railroad lines within the polder areas of Holland. Lorie has tabulated the records of 124 such borings, showing

[135] A. Rutot, "Le puits artesien de Blankenberghe," *Bull. Soc. Belge de Geol.*, Vol. II., 1888, *Mem.*, p. 261. This author has given equally illustrative records in later memoirs published in this *Bulletin*, Vol. VIII., 1894; Vol. XI., 1897.

the conditions between Enkhuizen, north from Amsterdam, and Dordrecht, south from Rotterdam, as well as in localities east and west from that line. It is unnecessary to give more than a few of these as in any group the same conditions are found. Eighteen borings are reported along the east and west line from Rotterdam to the Hook of Holland. Seven of these follow, the measurements being in meters and the numbers are those of the records:

		85.	87.	88.	89.	90.	92.	102.
1.	Sand and clay	4.5	3.9	3.2	6.0	5.1	2.5	4.5
2.	Peat	0.9	1.4	3.0	1.5	2.6	4 5	3.2
3.	Sand and clay	..	..	..	..	0.5	5.5	2.5
4.	Peat	..	..	..	..	0.3	1.0	0.5
5.	Sand and clay	..	..	..	..	6.0	..	0.1
6.	Peat	..	..	..	..	1.0	..	0.5
7.	Sand and clay	..	..	..	..	..	..	1.5
8.	Peat	..	..	..	..	..	..	1.0
9.	Sand and clay	..	..	..	..	..	..	1.2
10.	Peat	..	..	..	..	..	..	1.0

These exhibit the variations to a depth of 16 meters. The material in each case below the lowest peat bed in the column is sedimentary clay and sand. Peat was found in some localities at 19 meters, but it is never continuous to that depth, being always divided by sediments. The greatest continuous thickness found in any boring is 10 meters. At times the peat is replaced wholly by sediment and one can trace old river courses in which no peat was formed and which now are filled with the transported sediment. The records show the conditions in an area of 70 by 20 miles, throughout which one finds one or more beds of peat covered with a greater or less thickness of sediment. These are autochthonous, and they contain stems of trees rooted in the subsoil. The intervening deposits are often distinctly marine in many parts of Holland; a section by Lorie shows

		Meters.
1.	Peat	3.2
2.	Gray clay, sandy below, calcareous, marine diatoms below, plant remains in upper part	0.8
3.	Argillaceous sand with *Cardium* and *Scrobicularia*	5.9
4.	Black peat	0 5
5.	Tough grayish blue clay	1.1
6.	Black, hardly coherent peat	1.2

The portion of Holland considered in Lorie's tabulated records is not less than 1,500 square miles; a more extensive area in Belgium shows the existence of covered peat deposits and this condition reaches far over into France, for, at Cotentin in Normandy, the peat, 20 meters thick, is covered with 3 meters of marine sand. One has in this region an area, almost as great as that of the Everglades in Florida, in which the existence of buried peat bogs has been proved, some of them having been traced continuously in a great part of the region. How great the total area may be, has not been ascertained, but it is very much greater than that which has been studied in detail.

The change in structure and composition of peat, as the depth increases, has been referred to more than once in the preceding pages. Evidently the older the peat, other things being equal, the more thoroughly the material is disintegrated. If compacted by pressure and the removal of water, it assumes the appearance of brown coal and does not regain plasticity, as appears from the descriptions by Dawson and Lesquereux, to which many others might have been added. It is certain that some constituent, once soluble in water, has become insoluble, as soluble silica, once dried, becomes insoluble. When the deposit, exclusive of enclosed wood, has been reduced to mature peat, one must resort to chemical reagents and to the microscope in order to ascertain the component materials. Those bring to view a structure, a physical composition, which is wholly similar to that which Grand' Eury gives for coal studied after the same method. It is a mass of disintegrated fragments, held together by a fundamental material, much of which was originally flocculent. The older quaternary peats show much variation; that described by Dawson has little which suggests peat to the unaided eye; but there are others which so much resemble the newer peats that, were it not for the presence of extinct mammals and the great thickness of cover, one might hesitate before deciding that they are not of recent origin. There are still others, which in the several layers exhibit great variations, some being of comparatively unchanged peat, while the material in others has lost all of the original macroscopic features.

Among the latter group, the most noteworthy example is the Schieferkohle of Utznach, Dürnten and neighboring localities in Switzerland, which is interesting from the economic as well as the scientific point of view. Having been studied in great detail by several geologists, it will suffice as type. Some have thought that these deposits are post-glacial, in which case, they would possess the greatest possible interest to students seeking to ascertain the mode in which vegetable matter became converted into coal and gathered into beds. But the age remains unsettled; Heim[136] maintains that the Schieferkohle lies between moraines. The section in detail at Wetzikon and Utznach shows drumlines and erratic blocks of the last glaciation resting on fluvio-glacial gravels. The lignite, underlying the latter, 1 to 3 meters thick, rests on bowlder clay of the greatest glaciation. These lignites are autochthonous, full of *Betula alba,* the stems at times vertical and with their roots in the underlying bowlder clay.

Heer[137] in his earlier work discussed the Utznach and Dürnten deposits, but dwelt more in detail on the latter as, at that time, it was the better exposed. The lignite is 12 feet thick, rests on clay and underlies about 30 feet of sand and gravel. It is not continuous vertically, but is divided by 6 clay partings, in all about 2 feet. The lowest bench contains much wood together with cones of *Pinus abies,* which are not found in the upper benches. In each higher bench, one finds at the bottom, whole layers of mosses, felted together and pierced by reeds, while above are stems, lying in all directions, with roots, barks and fragments of wood, all pressed flat. The annual rings are distinct in many stems and in one Heer counted 100. Some coaled stems were seen, which he thinks may have been charred by lightning. The trunks are surrounded as in peat by a black-brown mass, which undoubtedly originated from decay of herbaceous plants, converting them into a pulp-like mass. This succession is repeated in every branch, but, in the topmost, stems are comparatively rare, mosses and reeds predominating.

[136] A. Heim in letter of May 23, 1911.

[137] O. Heer, "Die Schieferkohlen von Utznach und Dürnten," Zurich, 1858, pp. 7–11; "The Primeval World of Switzerland," *Eng. Trans.,* London, 1876, Vol. I., pp. 29, 30, 32; Vol. II., pp. 149–155, 157, 161–163.

The plants and the conditions are those of a peat moor. The mosses belong to the peat-forming group; the reeds and sedges are swamp plants to which also belongs the bogbean (*Menyanthes*) of which the seeds are abundant in both the coal and the partings. Spruce is present only in the lowest bench but birch and fir (*Pinus sylvestris*) are in the higher benches. The trees are those of the swamps. The animal remains belong in part to a swamp fauna, there being great abundance of insect wing-cases on surfaces of the peat and clay layers, while with them are shells of freshwater mollusks. The larger animals are mammals. Everything goes to show that this Schieferkohle is a compressed, dried out peat and the older opinion—that it originated from drifted wood—is incorrect.

In his later work, Heer gives additional facts respecting Dürnten and some noteworthy observations concerning other localities. At Dürnten, a wedge of sand and pebbles separates the main mass from a 6-inch layer of peat and stems above. The main portion is horizontal, while the thin layer dips toward the place of union and the sands overlying it have the same dip. At Unterwetzikon the lignite, underlying 12 to 30 feet of stratified sands and gravel, rests on a marl with freshwater shells. At Utznach, there are two beds, 5 and 3 feet, separated by 16 to 20 feet of light colored marly material, and the lignite retains its original horizontal position. At Morschwyl, the lignite is 2 feet thick, with vertical tree stems, the whole marly deposit, including the lignite, being 8 feet thick and underlying 26 feet of detritus. At another locality, the cover is 70 feet and the deposit is 3 feet, with vertical stems, 6 feet high and 3 feet diameter, extending into the marl above. This lignite underlies and overlies marl, the whole mass being about 16 feet thick. Heer gives a list of the plants recognized at the several localities and discusses their relations, showing that the grouping is clearly that observed in peat bogs of northern Europe.

v. Gümbel[138] studied this Schieferkohle from many places in Switzerland and southern Bavaria, his typical locality being Morschwyl. In both the partly loose peat-like and the partly dense pitchcoal-like portions, numerous horizontal-lying fragments of

[138] C. W. v. Gümbel, "Beiträge zur Kenntniss," etc., pp. 135–138.

boughs and stems were found, mostly conifers, birches, willows and alders, which in some cases resemble brown coal, in others, pitch coal. The peat-like character of the whole mass, as described by v. Gümbel, recalls the buried bogs of Ohio and Indiana. Treated with caustic potash, the looser portions become a soft, dense felted mass, in which the microscope detects as prevailing constituents, leaves of grasses with mosses. *Sphagnum* is the prevailing form. Fragments of wood are comparatively rare, though needles and twigs of conifers are not wanting. The denser portions need application of Schultze's test, a mixture of potassium chlorate and strong nitric acid, which must be allowed to act for a considerable time in order to separate the plant remains. These are the same as in the looser portions. But in addition are splinters of a deep brown structureless material, behaving as dopplerite. It fills cell-spaces in many plant-fragments; this textureless material is the Carbohumin. The numerous cones embedded in the mass are not deformed.

In passing from the Quaternary to the Tertiary, one finds increased difficulty in recognizing peat bogs; the conditions, observed in the older portions of recent bogs and in those of the Quaternary, are intensified by compression and by removal of the water, which kept in soluble condition the ulmic and humic constituents, while advancing chemical change has converted the whole mass into the mature condition. In fine, the amorphous plastic peat has become amorphous brown coal and only trunks of resistant wood remain to tell the story. Yet in some cases the resemblance is so great that little room remains for doubt. A typical instance is the great Senftenberg Miocene deposit, described by Potonié, to which reference will be made again on a succeeding page. To one familiar with the cypress swamps of the United States, there can be no question respecting the origin of that deposit. Aside from loss in plasticity of the peat, and its conversion into brown coal, the description given by Potonié would apply equally well to the white cedar swamps of New Jersey or to some of the *Taxodium* swamps of the Mississippi, where the peat is equally pure, the mud and silt having been strained out as the water passed through cane brakes.

Heer, in his "Primeval World of Switzerland," says that at

Dürnten, the Schieferkohle rests on a gray-white marl containing *Anodonta, Valvata* and *Pisidium*. That marly clay rests on the Oligocene Molasse, which holds a bed of lignite. The woody limbs are still distinct but the rest of the mass has been changed beyond recognition. Yet one finds traces of marsh plants in the overlying marls, while underlying the lignite is an undoubted lake-marl containing *Unio, Planorbis* and *Lymnæa*.

Conclusions.—In this presentation of the features characterizing peat deposits, some facts appear in notably bold relief.

1. Peat deposits vary in form from lenses to sheets; the former are of petty to considerable extent, fill depressions such as pond or small lake basins; the latter, often of vast extent, originate on approximately level areas, where drainage is imperfect. The bottom and top are apt to be irregular; the latter because of islands or sandy deposits but especially because of streams and shallow ponds; but the form of the bottom depends on that of the surface on which it rests. The thickness may show great variation; a few inches of peat at one locality may be continuous with a deposit, 10 or even 60 feet thick elsewhere. Great deposits are not continuous vertically; partings divide the bed into benches; those partings may be very thin, clay or sandy clay with much woody matter, merely desiccated peat wasted by exposure during a dry period, or they may be sediments, varying from films of clay to beds of sand, gravel or clay, loose or consolidated. Peat deposits, especially those of great horizontal extent, often bifurcate and, at times, the "splits" reunite. The underlying material may be clay or sand—usually clay or marl for the lens-shaped deposits, but very often sand or sandy clay for sheet deposits extending over great areas. Sand with slight admixture of clay becomes practically impermeable by absorption of humic acid.

2. Peat deposits are recognized by macroscopic features as far back as the middle Tertiary. Some of Post-glacial age and several thousands of miles in extent are buried under 3 to 30 feet of sediment; some Quaternary deposits underlie 30 to 120 feet of transported inorganic matter and the overlying deposits vary from fine

clay with plant impressions to fine or coarse sandstone, conglomerate or even breccia.

3. Many vast moors, such as those of the Netherlands and North Germany as well as great and small moors in the United States and elsewhere, are at only a few feet above tide. A very slight depression suffices to bring the surface below that level and to introduce marine conditions. In lowland areas, thousands of square miles in extent, one finds a marine deposit, with characteristic fossils, immediately overlying peat, which is sometimes continuous with a still living moor above high tide. In such areas, one finds occasionally a marine deposit, clay or sand, immediately underlying the peat. The overlying or the underlying material or both of them may be distinctly calcareous.

4. The passage from peat to the overlying deposit may be abrupt or it may be gradual through alternations of peat and sediment.

5. The channel ways of streams crossing the moors are traceable in borings after the moors have been covered with sediment; they contain little or no peat.

6. The peat deposit is not always homogeneous. Sapropel, organic mud, is the foundation in a great proportion of lake deposits in Europe and in some within the United States; it is probably absent at bottom of great sheet deposits; but it may occur as lenses in any part of the section, marking the sites of shallow ponds. Sapropel is an unimportant constituent of true peat, which is produced by water-loving land plants, the work of other types being a negligible factor. The several benches of a deposit may differ notably in structure and composition. Peats are laminated even when new, but under compression, the lamination is characteristic and the material has a coal-like appearance.

7. Peat varies greatly in purity. At times, it has less ash than is found in plants whence it is derived, owing to the action of organic acids on silica and other mineral constituents; in most cases it shows notable variations, both vertically and horizontally, that variation depending chiefly on extent of exposure to flooding by muddy waters. Peat often contains a considerable quantity of iron and calcium in combination with carbonic, sulphuric and phosphoric

acids. Alumina and sodium chloride seem to always be present, though the latter is in small proportion.

8. When mature, peat consists of minute fragments of plants, embedded in an amorphous substance, more or less flocculent, the whole cemented by an originally soluble substance, which fills clefts in the peat and at times clefts in the underlying deposit and, in the older peat, penetrates even the cell tissue of plant fragments.

9. In a very great number of peat deposits, one finds erect stems of trees, rooted in the underlying clay or sand. Within extensive areas, the peat mass is crowded with successive generations of trees, which had grown on the peat, their roots not penetrating to the soil below. In the case of the less durable woods, the interior has disappeared and the compressed bark remains; but the prostrated stems of the more durable or resinous woods have resisted decay and they have retained their form; yet in Quaternary peat, the flattening is more or less marked in all. Peat is not good soil for all kinds of plants even when dry, but, even when wet, it is the soil on which several types of majestic trees thrive best; when somewhat less wet, it is the habitat of some other great trees, which flourish, while peat accumulates around their stems.

10. Peat accumulates within the tropics wherever conditions of topography and humidity are favorable.

11. The deposits of true peat are autochthonous.

Buried Forests.

Long ago, erect trees with roots and at times with branches attached, were observed in the Coal Measures. Some geologists were convinced that the existence of these trees was proof that coal beds were formed *in situ*. The force of this argument seems to be recognized by some of those who favor the doctrine of origin by transport, for, in later years, every reported discovery of trees or forest buried *in situ* has been met with incredulity or worse. The writer does not share in the opinion that the presence of trees buried *in loco natali* is of serious import as an argument, directly, either for or against any hypothesis respecting the mode of coal bed formation; but, in this, he apparently differs from so many geologists, that it may be well to supplement the references to buried swamps by some notes upon buried forests.

Russell's[139] description of conditions on the Yahtse river of Alaska relates that the stream, issuing as a swift current from beneath the glacier, has invaded a forest at the east and has surrounded the trees with sand and gravel to a depth of many feet. Some of the dead trunks, still retaining their branches, project above the mass, but the greater part of them have been broken off and buried in the deposit. Other streams, east from the Yahtse, have invaded forests, as is indicated by dead trees standing along their borders. Where the deposit is deepest, the trees have already disappeared and the forest has been replaced with sand flats. The decaying trunks are broken off by the wind and are buried in prostrate position. This deposit, consolidated, would resemble closely a Coal Measures conglomerate.

The submerged forest on the Columbia river of Oregon was observed first by Lewis and Clark and it was examined almost 30 years afterwards by Wilkes; but Newberry[140] was the first to study it in detail. He found the river bordered at intervals on each side by the erect but partially decayed stumps of trees, which project in considerable numbers above the surface of the water. These stumps belong to the Douglas spruce, which still covers the mountain slopes. The dam at the Cascades is a conglomerate, penetrated by threads of silica, often filling cavities with agate and chalcedony. It contains many trunks of trees, some of them merely carbonized, others silicified, while still others show both conditions. These trunks have a microscopic structure closely resembling that of the Douglas spruce. The writer may add that similar conditions exist in the buried forest near Salem on the Willamette river in the same state.

Along the whole Atlantic coast from Nova Scotia to Florida, one finds sunken forests now buried under peat or sediments. Dawson described one seen on the coast of Nova Scotia at 25 to 30 feet below high tide, where the stumps were rooted in material, having

[139] I. C. Russell, "Second Expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Survey, 1893. Pt. I., p. 14, Pl. XII.

[140] J. S. Newberry, Pacific Railroad Explorations, Vol. VI., 1856, "Geological Report," p. 56.

all the characteristics of a forest soil, and were scattered irregularly as in an open wood. E. Hitchcock asserted that buried forests are numerous along the coast of Massachusetts; cedar, oak, maple and beech trees are found in the harbor of Nantucket, some erect, others prostrate and all of them surrounded by an imperfect peat. This forest is buried under 4 feet of sand. Cook[141] has described many buried forests in New Jersey, the most interesting being those now concealed under the tidal marshes. At one locality, a ditch was digged to drain some large tidal ponds; it exposed nothing but mud and grass roots; the outrush of water at ebb tide widened this narrow drain to 70 feet and scoured the bottom, which proved to be thickly set with pine, white cedar and gum stumps, standing upright and giving every indication that they were where they had grown.

Tuomey[142] has described an area of tidal marsh, which is covered with live-oak trees, some standing, but most of them prostrate. These are certainly not where they grew and it is equally evident that they have not been transported. Originally, this mud flat, now littered with shells of oysters and mussels, was covered with sand hills, of which some remain. During storms, waves broke over the peninsula, washed away the sand hills and left the trees, some of which remain standing because supported by their broad roots. At another locality, a great white cedar swamp shows living trees, but, toward the river, the trees are dead and the continuation of the mass under the river shows stumps in place. Encroachment of salt water killed the dense undergrowth of the swamp—decomposition of the exposed peat advanced and the trees broke off at the "air line." He refers to many places where the saltwater invasion and subsequent change in the swamp material caused destruction of the white cedar or cypress forest; sediment covered the stumps and another growth followed.

Agassiz,[143] observed a submerged forest at the mouth of the Igurapi Grande, which clearly belongs to the recent epoch.

[141] G. H. Cook, "Geology of New Jersey," 1868, pp. 350, 352, 354, 355, 360.

[142] M. Tuomey, "Report on the Geology of South Carolina," Columbia, 1848, pp. 194–200.

[143] L. Agassiz, in "A Journey to Brazil," Boston, 1868, pp. 434, 435.

"Evidently this forest grew on one of those marshy lands constantly inundated, for between the stumps is accumulated the loose felt-like peat characteristic of such grounds and containing about as much mud as vegetable matter. Such a marshy forest, with the stumps of the trees still standing erect on the peat, has been laid bare on both sides of the Igurapi Grande by the encroachments of the ocean. That this is the work of the sea is undeniable, for all the little depressions and indentations of the peat are filled with sea sand and a ridge of tidal sand divides it from the forest still standing beyond. Nor is this all. At Vigia, immediately opposite to Souré, on the continental side of the Para river, just where it meets the sea, we have the counterpart of this submerged forest. Another peat bog, with the stumps of innumerable trees standing in it and encroached upon in the same way by tidal sand, is exposed here also."

Forests buried during the recent epoch are such familiar and commonplace features that further reference to them is unnecessary.

Forest beds of Quaternary age have been reported by observers in many parts of the world. Reference has been made already to the great forest bed of southwestern Indiana, buried under 60 to 120 feet of later glacial material. McGee[144] has described a forest bed, which divides the glacial deposits in northeastern Iowa. It was much disturbed during a later advance of the ice. Accumulations of logs, stems, grasses and peaty soils occur at many horizons in both the upper and the lower till, but they are in largest volume and least disturbed condition at the junction of the two drift sheets. The distribution is related to that of the upper till. Where the glaciation was most energetic, the deposit is absent; where less energetic, it is present but broken up badly; toward the eastern part of the area, the disturbance decreases and the deposit is found in normal condition with everything *in situ*. There one finds the peaty soil with stumps and roots all evidently in place.

Quaternary forest beds are many in Europe. It suffices to quote from J. Geikie,[145] who has described the condition in Great Britain.

"The broad facts then are these: at a depth from the surface, varying from 20 to 60 or 70 feet, occurs a layer of peaty matter enclosing and covering forest trees, the stools of which are often rooted in an ancient soil. Above this buried land surface appear lacustrine, or estuarine or, as

[144] W J McGee, "The Pleistocene History of Northeastern Iowa," Eleventh Ann. Rep. U. S. Geol. Survey, 1891, Pt. I., pp. 199–577. Citations from pp. 486–496.

[145] J. Geikie, "The Great Ice Age," 3d Ed., p. 405.

the case may be, marine deposits. Next comes a second forest layer, overlaid by similar accumulations. It is the second forest bed, which is so frequently exposed upon the present fore shores."

In succeeding pages this author gives detailed evidence respecting the stratigraphic relations of forest beds at the different localities.

Passing from the Quaternary to the Tertiary, one finds less frequent notices of buried forests, owing, of course, to lack of exposures. Lyell,[146] after describing the buried cypress swamps of the Mississippi delta, mentions the Tertiary deposits at Port Hudson, which had been seen by Bartram and, at a later date, described by Carpenter. Bartram observed that the erect cypress stumps seemed to be rotted off at 2 or 3 feet above the spread of the roots and that their trunks, limbs, etc., lie in all directions about them. When Lyell visited the locality, the water was too high to permit study of the lowest part of the section and he gave Carpenter's statements respecting it. At the bottom of the bluff, is a buried cypress swamp, containing sticks, leaves and fruits in horizontal laminæ, with filmy layers of clay interposed. With these are great numbers of erect stumps of the large cypress, sending roots into the clay below. At 12 feet higher is a second deposit, 4 feet thick, consisting of logs and branches, half converted into lignite, along with erect stumps. Above this are more than 50 feet of clays, containing two layers of vegetable matter.

Hilgard[147] gives some details respecting what is evidently the lower Port Hudson bed as seen between that place and Fontania. The section in the bluff is

	Feet.
1. Yellow loam	8 to 10
2. White and yellow hardpan	18
3. Orange and yellow sand	8 to 15
4. Greenish or bluish clay	7
5. White silt or hardpan	18
6. Green clay with calcareous and ferruginous concretions, sticks and leaf impresions	30
7. Brown muck or blue clay with cypress stumps	3 to 4

[146] C. Lyell, "A Second Visit to the United States," etc., Vol. II., pp. 134, 178, 179, 180, 192, 272, 273.

[147] E. W. Hilgard, "On the Geology of Lower Louisiana," Smithson. Contrib. No. 248, 1872, pp. 5–7, 9, 11.

"These stumps evidently represent three or four successive generations, growing at higher levels as the surface of the swamp was raised by deposition." Some of them are large and the wood is so hard that it is difficult to detach a piece with the hatchet. No. 5, in some places, is a river alluvium and at times resembles a sandbar. It frequently contains great quantities of driftwood.

The cypress stumps in No. 7 are well preserved and hard, but the driftwood in No. 5 is soft and spongy. When water-soaked and resting on the ground it is visibly flattened by its own weight; one stroke with the hatchet will sever a trunk, 20 inches or more in diameter. But if this soaked material be exposed to continuous sunshine, it not only loses water but also contracts into hard shining lignite, with conchoidal fracture and exhibiting to the eye scarcely a trace of the original structure. A trunk, 6 or 8 inches in diameter, when thus dried, forms a contorted coal layer not more than half an inch thick. The exposed portion of a trunk may be transformed in this way, while the portion, remaining embedded, retains the original features. These changes are very like those seen in the lignite at Putznach as described by Bischof; there is evidently a change from soluble to insoluble in some constituent of the trunk. Hilgard[148] had traced the deposit underlying the Orange sands through a great area in southern Mississippi and the features seem to be the same throughout. It "cannot be better described than as the soil of a cypress swamp, with its muck, fallen trunks, stumps, roots and knees. Of these there are evidently several generations, separated by more clayey layers of muck."

Eldridge[149] mentions a deposit of Eocene lignite in Alaska containing 10 to 15 beds varying in thickness from 6 inches to 6 feet. The ash is from 1.85 to 10.68 per cent. The lignite of these beds resembles a mass of carbonized wood. Stumps, 1 to 2 feet in diameter, are common, standing vertical to the bedding. Their appearance as well as the abundance of slivers and other carbonized

[148] E. W. Hilgard, "Report on Geology and Agriculture of the State of Mississippi," Jackson, 1860, pp. 152, 153, 155.

[149] G. H. Eldridge, "Reconnaissance in the Sushitna Basin, Alaska," Twentieth Ann. Rep. U. S. Geol. Surv., 1900, Pt. VII., pp. 21–23.

material suggests that these coal beds originated in a mass of decayed swamp vegetation. Locally, portions of the mass have lost the woody structure and resemble the higher grades of lignite, shading into bituminous coal. But, as a whole, this coal is in its youth and Eldridge thinks it doubtful if a younger example of coal can be found—peat excepted.

Darwin[150] saw in Chili a petrified forest in Tertiary rocks. Eleven trunks were silicified and 30 to 40 were converted into coarsely crystallized white calcareous spar. They had been broken off abruptly, the vertical stumps projecting a few feet above the ground. They were from 3 to 5 feet in circumference. "The volcanic sandstone, in which the trees were embedded and from the lower part of which they must have sprung, had accumulated in thick layers around their trunks; and the stone yet retained the impression of their bark."

The Miocene brown coal deposit at Gr. Raschen near Senftenberg has been referred to on a previous page: Potonié's[151] description is that of a buried forest closely resembling those of New Jersey. It is very similar to the buried cypress swamps and forests of the southern United States, for *Taxodium distichum* is the dominant tree. As in the white cedar and cypress swamps, one finds in this brown coal deposit, 10 meters thick, successive generations of trees. The fuel is mined in open quarry and Potonié's plate shows the erect stumps distributed on the surfaces of several benches as they stood in the old forest, while the walls of the benches exhibit prostrate trunks in the intervening spaces, precisely as one sees them now on the surfaces of the forested swamps in America. These stumps, one third of a meter to nearly 4 meters in diameter, are, like those described by Cook and others, rooted in the peat, now converted into brown coal of excellent quality, as good as that which will come from the Dennisville peat in New Jersey.

There are few recorded observations of buried forests in the Mesozoic rocks; in very great part, those rocks were marine: The

[150] C. Darwin, "Journal of Researches," New York, 1846, Vol. II., pp. 85.

[151] H. Potonié, "Ueber Autochthonie von Carbonkohlen-Flotzen und des Senftenberger Braunkholen-Flotzen," *Jahrb. k. preuss. geolog. Landesanstalt.*, 1895, Separate, pp. 19–24.

latest Cretaceous in the United States is mostly of freshwater origin and it contains many coal beds; but there is no positive evidence that buried forests exist. Long ago, the writer saw, in New Mexico, great numbers of stumps and trunks in a sandstone, apparently of this age, and the same deposit has been mentioned by others; but there is no evidence on record to show that the stumps are *in situ.* Lyell was convinced that he saw vertical stems of *Equisetites* in place at a locality in the Triassic field near Richmond, in Virginia, but his observations are not sufficiently in detail to justify one in accepting them as evidence. It has been suggested that slender stems such as those of *Equisetum* or *Calamites* could not stand, while a sandstone accumulated around them; but the suggestion is without basis. The writer has seen slender canes on the Gulf shore of the Mississippi delta, which had been killed many years before by an invasion of salt water; but they were still erect, though sediment had accumulated around them to the thickness of several feet.

The "dirt bed" of the isle of Portland, belonging to the Upper Jurassic, was described long ago by Mantell.[152] The uppermost Oolite stratum is a layer, one foot thick, of very dark friable loam, which seems to have been a bed of vegetable mould. It contains a large proportion of earthy lignite and also, like the modern soil of the island, waterworn pebbles and stones. This is the "dirt bed" of the quarrymen and upon it are branches and stems of conifers and plants allied to *Cycas* and *Zamia.* Many of the trees and plants stand erect as if petrified while growing undisturbed in their native forests. Their roots extend into the "dirt bed" and their trunks into the superincumbent limestone. At the time of Mantell's visit, a large area had been exposed by stripping:

"Some of the trunks were surrounded by a conical mound of calcareous earth, which had evidently, when in the state of mud, accumulated around the stems and roots. The upright trunks were in general a few feet apart and but 3 or 4 feet high; they were broken or splintered at the top, as if the trees had been snapped or wrenched off at a short distance from the ground. Some were 2 feet in diameter, and the united fragments of the prostrate trunks indicated a total length of between 30 and 40 feet. In many examples, portions of branches remained attached to the stems."

[152] G. A. Mantell, "Geological Excursions Around the Isle of Wight," 3d Ed., London, 1854, pp. 287, 288.

Green,[153] visiting the locality some years afterward, remarked that the conditions recall those in interglacial buried forests of Great Britain; for the "brashy" soil, containing the stools of large trees, with here and there prostrate trunks, underlies a limestone carrying estuarine fossils. Other "dirt beds" appear occasionally, showing that the condition was repeated at some localities.

Passing to the Palæozoic, one finds many references to forests and trees buried in place, for excavations and explorations are extensive and the localities, unlike most of those in the Mesozoic, are in regions where scientific observers abound.

Al. Brongniart[154] saw at the mine du Treuil, near Saint-Etienne, a sandy bed, 10 to 13 feet thick, containing "a true fossil forest of monocotyledonous vegetables, resembling bamboo, or a huge *Equisetum,* as it were, petrified in place." These are erect. There were two types of stems; one cylindrical, jointed, striated parallel to their edges and the cavity filled with rock like that which surrounds them. The rarer forms are hollow cylindrical stems, diverging at the lower end "after the manner of a root but without presenting any ramification." Gruner[155] notes the existence of another forest at the same mine, but much lower in the section. The trees are *Syringodendron* and the roots rest on the coal. Brongniart refers to other localities, where vertical stems had been seen, and he cites Charpentier, who explained one rather notable case as due to landslides. Support for this conception was found in the débâcle of Lake Bagne, during which great trees were carried down with the mass and deposited in the original vertical condition position on the plain of Martigny. But Brongniart maintained that such occurrences must be rare, whereas vertical stems are found at many localities. At Treuil, as well as near Saarbruck, one finds not merely a single large trunk but many—a forest of slender stems, which have preserved parallelism among themselves. It is perhaps more difficult to conceive that sandy rock could envelop them after removal without destroying

[153] A. H. Green, "Geology," Part I., London, 1882, pp. 252, 253.

[154] Alex. Brongniart, "On Fossil Vegetables Traversing the Beds of the Coal Measures," *Ann. des Mines*, 1821. Trans. by H. de la Beche in "A Collection of Geological Memoirs," 1836, pp. 210, 216.

[155] L. Gruner, "Bassin houiller de la Loire," 1882, p. 226.

them, than to conceive that the deposit was made between them where they grew and were firmly rooted.

The discovery, near Manchester, England, of erect stumps, led several members of the London Geological Society to visit the locality. Hawkshaw[156] in 1839 and 1840 described five erect stumps and he was firmly convinced that they were in the place of growth. Bowman[157] in discussing the same occurrence, asserted that the loss of roots in the Manchester specimens was due to a process of fermentation. He combatted the notion that floated trees would remain erect, maintaining that, when they ceased to float, they would turn over. Several years afterward, Beckett and Sparrow[158] discovered some erect stumps near Wolverhampton, England. Beckett removed the coal attached to one of the trees. The stump was perfectly "bitumenized" but broken off at about 2 inches above the top of the coal, the inner portion being hollowed out to about the level of the coal. The stem was not flattened; it was approximately 4 feet in circumference and the roots spread out in a broad mass. The trunk and roots were covered with one half inch of bark, converted into brighter, more compact coal than that of the interior which was a mixture of coal and shale. The coal bed is about 5 inches thick. A few years later, Jukes[159] visited this locality with Beckett and, in writing about the stumps, he conceded that "they certainly looked as if they had grown there, and perhaps they may have done so, but even so, it by no means settles the question" [of origin of coal beds].

Beckett expressed no opinion respecting the original relations of the forest, but his paper is followed directly by Ick's[160] description, which is more in detail. The surface of the coal had been exposed by stripping in a rudely triangular space of about 2,700 square yards. Upward of 70 stumps were seen on this terrace, some of them more

[156] J. Hawkshaw, *Proc. London Geol. Soc.,* Vol. III., pp. 140, 269.

[157] J. E. Bowman, *Ibid.,* pp. 270, 271, 274.

[158] H. Beckett, *Quart. Journ. Geol. Soc.,* Vol. I., 1845, pp. 41, 42.

[159] J. B. Jukes, "The South Staffordshire Coal-field," 2d Ed., 1859, p. 201, footnote.

[160] W. Ick, "A Description of Numerous Fossil Dicotyledonous Trees at Parkfield Colliery near Bilston," *Ibid.,* pp. 43–45.

than 8 feet in circumference, all broken off close to the coal, while the prostrate trunks lie across each other in every direction. These trunks, 15 to 30 feet long, are invariably flattened to the thickness of one or two inches, but the bark is distinct on both sides. The bark is well preserved on the stumps, converted into bright coal, while the interior or woody part is dead looking, with dull luster like cannel. The stumps seldom rise above the surface. In some cases the diverging roots can be followed for nearly a yard, but they cannot be traced into the underlying shale. In some cases, *Calamites* are crowded between the trunks; *Lepidodendron* and *Lepidostrobi* are abundant on the surface, while among them one finds occasional remains of fishes. A noteworthy feature is that there are three coal beds within a vertical space of 12 feet, each of which shows on its surface the remains of an ancient forest—and the same beds are exposed a mile away. Beckett says that the coal, when "broken with the grain," shows faint impressions of *Calamites* and reed-like plants. Ick recognizes that "the position of the trees in each bed of coal seems almost to preclude all doubt of their having grown and perished on the spot where their remains are now found, and the roots are apparently fixed in the coal and shale, which was the original humus in which they grew."

Binney[161] described the great *Sigillaria* stump, discovered at 7 miles east from Manchester and now in the museum of Owens college. The stump is filled with dark-colored fireclay but the roots with a different material. The dark fireclay floor was penetrated to about 3 feet by the stem and roots, the latter being, in part, directed upward.

De la Beche[162] remarks that actual observations of rooted stems are comparatively few because exposures are few. He and W. E. Logan saw many vertical stems in a sandstone at a Welsh colliery. The directly underlying shale contained ferns and leaves of other plants distributed "around in the same manner as leaves and other parts of plants may be dispersed around stems of trees in muddy

[161] E. W. Binney, "Description of the Dirkenfield *Sigillaria*," *Quart. Journ. Geol. Soc.*, Vol. II., 1846, p. 390.

[162] H. T. de la Beche, "The Geological Observer," Philadelphia, 1851, pp. 482–485, 497.

places at the present day." The sandstone laminæ, by their arrangement, suggest the washing up of sand around stems in shallow water with small waves. This is shown more clearly at a locality in the Newcastle district, where one can determine the direction whence the current came by position of laminæ marking eddies behind the stems. Prostrate stems, often of same species with the vertical stumps, recall the prostrate trees among stumps in "submarine or sunken forests."

Dawson[163] first visited the South Joggins region in 1852, accompanied by Lyell. Somewhat later, he studied the section in great detail and gave his results in a series of memoirs published by the London Geological Society; but the final discussion appeared in the second edition of his Acadian Geology. Seventy coal horizons, some of them merely "fossil dirt beds," were seen in a vertical section of 4,700 feet and besides these there are many horizons at which rooted stumps were seen. Drifted trunks were observed in the sandstones, but those are neglected here, reference being made only to such remains as were associated with Stigmarian underclays.

Erect stumps were seen in the thin shale roof of Coal 13. In the interval of 38 feet between Coals 16 and 17 are several Stigmarian clays, one of which supports large stumps of *Sigillaria* with plant remains about their foot; the red shale roof of Coal 19 shows an erect *Sigillaria*, while erect *Calamites* stems are present over Coal 21 and a Stigmarian soil at some distance below Coal 22 bears a number of erect *Sigillaria* stumps. Division IV. shows erect stems of *Sigillaria, Lepidodendron* and *Calamites* at 44 horizons in a vertical section of 2,539 feet; several of the underclays, bearing erect stumps, underlie thin coal beds and, in at least one case, Coal 15, the erect stumps are associated with rain marks and footprints, clear evidence of sub-aerial position. At one horizon, the stumps yielded three species of batrachians with land shells and insects; those stumps are rooted in coaly shale forming the roof of a coal bed. "A coaly stump and an irregular layer of mineral charcoal, arising apparently from the decay of similar stumps" were seen in Coal 33*a*, while above that bed in a reddish shale is "a patch of gray sand-

[163] J. W. Dawson, "Acadian Geology," 2d Ed., London, 1868. pp. 150–179.

stone, interlaced with *Stigmaria* roots, as if the sand had been prevented from drifting away by a tree or stump." The Millstone Grit, in three divisions and somewhat less than 6,000 feet thick, shows erect *Sigillariæ* in the lower portion, but most of the stems occurring in the sandstones are clearly driftwood.

One must keep in remembrance that Dawson's observations were made on the outcropping face of the beds along the coast; one may only conjecture what might be seen if some of the old soils were stripped as was the coal at Parkfield colliery.

Robb[164] described the rooted stump of *Sigillaria*, seen by him in the roof of a coal mine. The roots cross the slope, which is 11 feet wide; the conditions are shown well in the plate accompanying his report. He observed many *Sigillaria* stumps with their attached roots reaching into the coal seams. He notes one case, where a coal parting contains the roots of an erect tree, "which had apparently forced the layers asunder, 6 or 8 inches, for several feet from the extremities of the roots, beyond which the layers of coal unite again." In another, "where a large upright stem appears rooted in a coal seam, the latter seems to have been actually bent down by the superincumbent weight and, at a little distance, to have resumed its normal attitude."

Gosselet studied[165] the occurrence of erect stems at various levels in a vertical section and discussed their bearing upon the formation of coal beds. At Lens, there are three coal horizons within a vertical distance of 42 meters—Alfred, Leonard and Louise, with thickness respectively of 1.4, 1.6 and 0.6 meter. In the one meter thick shale under the Alfred, overlying an irregular *passée,* he saw two trunks, one resting on the *passée,* with the underlying coal slightly depressed, while, above, it terminates abruptly in a faux-mur, 5 centimeters thick, in direct contact with the coal. No roots could be traced. Five trunks were seen in the Leonard; one evidently had been floated in and a second was too indefinite for determina-

[164] C. Robb, Geol. Surv. Canada, Rep. Progress, 1874–5, pp. 196, 203, 204, 235, 237.

[165] J. Gosselet, "Note sur les troncs d'arbres verticaux dans le terrain houiller de Lens," *Ann. Soc. Geol. du Nord.,* Vol. XXIII., 1895, pp. 174, 175, 177–179, 181.

tion. Of the other three, two were implanted in a thin mur-like deposit covering the coal; the roots of one, a *Sigillaria,* spread out in the clay, but the roots of the other could not be traced. The roots of the third, in the coal, could not be recognized as *Stigmaria,* but they extended horizontally as clay masses covered with coal. The roots had been filled with sediment. Eight stems were seen in the Louise. Three rose directly from the underlying shale and crossed the mur, which is 60 centimeters thick; one was cut off abruptly at the coal and the others were broken off just before reaching it. The remaining five are in the roof. One is indefinite, but the others expand at the base and their rootlets are put forth into the shale. These erect trees, throughout, were *in situ;* all were vertical to the bedding. If they had been transported, they would have been inclined in direction of the current. Transported trunks were seen at various horizons but, in the cases described, the trunks were fixed in place by their roots, wherever the roots were seen. This Lens locality is in the great Westphalia-France-Belgium field, a paralic area.

Gosselet refers to conditions in the Banc des Roseaux at Commentry, where trunks are seen arranged in all directions, vertical, inclined, prostrate, and he compares them with those resulting from ravages of a hurricane in the forest of Mormal. There, many of the trees were prostrated; some, held by their roots, were inclined; while a small number remained erect—the conditions bearing remarkable resemblance to those observed at Commentry. His conclusion is that, where one sees the mur rich in rootlets of *Stigmaria,* he may regard it as a soil in which trees spread their roots. If the tree does not rise above the mur, it is because it has been destroyed by carbonization to furnish its elements, in part at least, to the coal bed. When the trunk is cut off sharply at coal or mur, it may be that the deposits were made so slowly that the trunk rotted off at the water-surface. He quotes Fayol as showing that at times one may prove the presence of erect trunks in the coal itself, but usually they are fused with the mass.

In this connection, it is well to recall the fact that Potonié[166]

[166] H. Potonié, "Die Entstehung der Steinkohle," etc., 1910, pp. 134–136.

found frequent occurrence of *Stigmaria in situ* at Commentry. One notable discovery was that of a stump, whose roots spread out in an area of 6 meters diameter and retained their minute appendages. According to Renault, the branches extended farther but they could not be followed. Fig. 46, copied from Renault's description, justifies Potonié's remark that, if this be a transported tree, one must believe that it and the fine mud enclosing it had been transported together and deposited in the original position.

Schmitz[167] examined 33 erect stumps exposed in the roof of the Grande Veine of the Liége basin. The coaly crust, sometimes one centimeter thick, and the scars suggest that the plants are *Sigillaria.* The stumps are in a space of 2 by 95 meters, giving for each plant 5.6 square meters, a condition favorable to the belief that they are *in loco natali.* But he found that the trunks are all cut off at the coal bed; most of them show the enlargement belonging near the roots, so that one cannot suppose that the trees extended downward through the coal to the mur. On the other hand, the transition from coal to sterile rock above is barely one centimeter of coaly clay, so that they could not have been rooted in the toit. The laminæ of this faux-toit contain many impressions of twigs of lycopods and *Equisetites.* Four of these pass under the bases of four erect trunks. This led Schmitz to think it impossible that the trunks were *in loco natali;* for if those four were not, there is no reason to suppose that the others were. To explain the condition, one must invoke transport. But, in a later paper to be considered in another connection, he gives the results of a more detailed study, which led him to recognize that the abrupt cutting off at the base was due to slips, which explained the presence of plant impressions under the ends of the free trunks.

Grand' Eury[168] summed up the results of his long study in a memoir presented at the Paris meeting of the Geological Congress,

[167] G. Schmitz, "Un banc à troncs-debout aux charbonnages du Grand-Bac," *Bull. Acad. Roy. de Belgique,* 3me Ser., Vol. XXXI., 1896, pp. 261–264.

[168] C. Grand' Eury, "Sur les tiges debout, les souches enracinées, des forêts et sous-sols des végétations fossiles et sur le mode et le mécanisme de formation de couches de houille du bassin de la Loire," *C. R. Cong. Geol. Intern.,* 1900, Vol. I., pp. 523–530.

drawing his illustrations mainly from conditions in the Loire basin. He exhibited twelve charts showing rooted trees and stumps discovered near Saint-Etienne during the preceding decade. Trees and stumps with roots attached were found belonging to *Stigmaria, Syringodendron, Stigmariopsis, Sigillaria, Calamites, Calamodendron, Psaronius, Cordaites* and other forms. In several cases, the leaves still remained attached. The arrangement of the roots depended somewhat on the soil in which they grew. Many times the more yielding soils permitted the roots to grow downward while in clays they tend to spread horizontally. Roots of *Stigmaria,* usually, those of other plants, frequently, are interlaced in such manner as to leave no room for doubting that they are *in loco natali.* The soils of vegetation are distinct, for the roots are woody, herbaceous, or of several kinds, occurring in groups or singly, often interlaced, sometimes spaced but never scattered. They are therefore in place. Where there have been successive generations, the roots of the newer generations sometimes penetrate the stumps of their predecessors and in many cases pierce impressions of plants lying in the shale, through which they pass. The secondary roots of several types are thoroughly distinct at varying levels, while the creeping rhizomas at the base still remain attached to the stem; and one often finds buried at the foot of rooted trees the branches, leaves and fructifications which were detached during their growth.

Grand' Eury's conclusion is that Carboniferous plants were arborescent marsh forms, living as those in the Dismal Swamp, the foot and adventive roots in the water, with the stock and rhizomas creeping on the bottom. They could live either on the area of increasing deposit or in stagnant water. The fossil forests have no continuity; they disappear in all directions, often being reduced to mere groves.

It is unnecessary to give further illustration. One desiring to pursue the matter will find in Goeppert's "Prize Essay" a full statement of all information available at that time for eastern Germany, with full discussion. His studies, in some respects, are as interesting as those by Grand' Eury. Lyell, R. Owen, Lesquereux and Newberry have given examples for the United States.

The occurrence of drifted logs and clumps of vegetation is a phenomenon as familiar as that of buried forests; indeed, in the nature of the case, it is more familiar, as coarse rocks are more widely spread than are the coaly deposits. The battered snags of the Missouri-Mississippi and the logs scattered through the delta silts; the similar accumulations in tertiary deposits of the Missouri and Mackenzie; in the London Clay and on the New Siberia islands; the irregular pots of lignite in many places on the continent of Europe; the driftwood in our Newark formation; and the vast abundance of snags, logs and branches in sandstones of the Coal Measures in Europe and America; all bear witness, as do the buried forests, that conditions have undergone no material change since the closing epochs of the Palæozoic. These drifted materials are everywhere distinguishable from plants buried *in situ,* for they have been deprived of all tender parts; of the harder woods in Carboniferous times there are few traces except decorticated stems, casts of the interior, indeterminate forms grouped under *Knorria, Sternbergia* and some other names.

Conclusions.—It is strange that there should be such intense unwillingness to accept evidence in favor of the existence of ancient forests. Reasoning from existing conditions, one would have room for disappointment if such forests were not discovered in the older rocks; yet some authors seem to believe that one is chargeable with overcredulity if he regard buried stumps as rooted in place when they occur in the Coal Measures and his proof is demanded as emphatically as though he had asserted that man's normal position is with his head on the ground and his feet pointing skyward. The abrupt termination of stumps on the coal and the absence of roots are, for some, positive evidence that the trees are not *in loco natali,* though the condition is that which must come about in the cypress swamps of this day; the number of prostrate trunks predominates over that of erect stumps, and this is taken as evidence that all alike were transported; yet every great forested swamp shows that broken and overturned stems fall to be preserved in moist surrounding, while many stumps remain exposed to atmospheric action and, in large part, decay. The very presence of the stump itself is taken to be evidence that it was transported, because one cannot believe that it would resist decay long enough to permit accumulation about it; yet the condition is familiar, for even the slender canes of the Mississippi delta, killed by salt water invasion, remain standing after they have been surrounded by several feet of silt. The filling of stumps by sand or clay is regarded as evidence that the change occurred after complete entombment in the mass of transported material; yet Potonié has shown that stumps on the shores have been found with the decayed interior replaced with sand even into the roots.

Some authors have laid no little emphasis on the Martigny débâcle as showing that landslides may explain those buried forests, whose *in situ* appearance cannot be denied. But aside from the fact that landslides are wholly exceptional and for the most part of limited extent, one may not utilize them as an explanation, unless it be supposed that, during the Carboniferous, landslides could occur amid conditions which would make them impossible now. According to some authors, the great coal areas were level regions; according to others, they were water basins, surrounded by a vast expanse of level area, forested or swampy. Under such circumstances a landslide like that of Martigny or even like that on the lower Adige could affect only the far away border area. But, in any event, the evidence of a landslide would be unmistakable; there would be no room for conjecture. The rock of the slide would be different from that at the same horizon a little distance away; and there would be ample evidence of disturbance in the underlying rocks, produced by downrush upon the water-soaked materials; certainly evidence of the débâcle would not be wanting. But no such evidence has been reported from any locality; on the contrary, where detailed descriptions have been given, one finds that the bedding is undisturbed and the conformability is complete. Equally, the buried trees are not relics of floating islands such as those of the Amazon and Congo, for they are not associated with filled valleys, but stand in and on rock of the type prevailing at the horizon for long distances.